FLUID LIFE
EQUIPMENT RELIABILITY SERVICES

Oil Analysis Basics & Data Interpretation Workshop

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Agenda

- **Fundamentals of Lubricants**
  - **Lubricant Functions**
  - Lubricating Oil Films
  - Oil Properties
  - Base Oil Types
  - The Functions of Lubricant Additives
  - Grease Properties
- Contamination Sources and Control Strategies
- Oil Sampling Basics
- Sample Registration
- Data Interpretation

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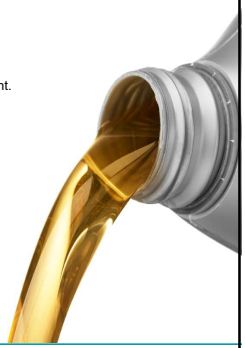
Lubricant Functions

- Why do we need Lubricants?
  - Reduce Friction.
    - This is the primary function of a lubricant.
  - Support a Load.
  - Remove Heat.
  - Neutralize Acidic By-products.
  - Prevent Corrosion.
  - Prevent formation of:
    - Carbon Deposits
    - Varnish
    - Sludge



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Lubricating Oil Film

- Hydrodynamic Lubrication
- Mixed Lubrication
- Boundary Lubrication
- Elastohydrodynamic (EHD)
- Hydrostatic Films

Image courtesy Imperial Oil

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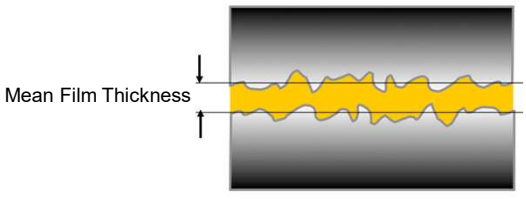
Lubricating Film

- The interacting surfaces are separated by a lubricant with an oil film of varying thickness.



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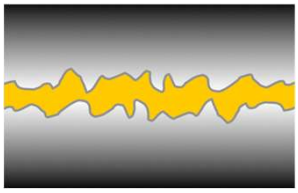
Hydrodynamic Lubrication

- Complete oil film with no surface contact.
- Film thickness depends on viscosity, speed, pressure or load.

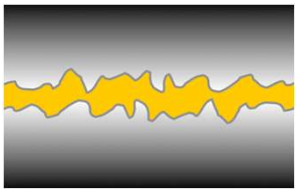


$\lambda > 4$

7

Mixed Lubrication

- Since the specific film thickness equation uses mean values, some asperities may still contact each other when the λ is equal to or greater than 1.

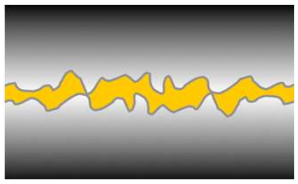


$1 < \lambda < 4$

8

Boundary Lubrication

- Significant asperity contact, further protection required from anti-wear or extreme pressure additives.



$\lambda < 1$

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Elastro-Hydrodynamic (EHD)

- Extremely high contact pressures produce a solid film that causes elastic deformation of the surfaces.
- Occurs in both anti-friction bearings and gears.

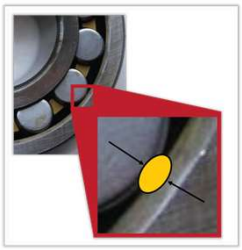

Image courtesy Imperial Oil

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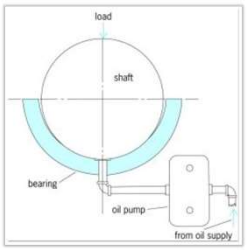
Hydrosatic Films

- Oil pressure supplied from an external source lifts and supports the load.
- No relative motion is required to produce an adequate oil film.



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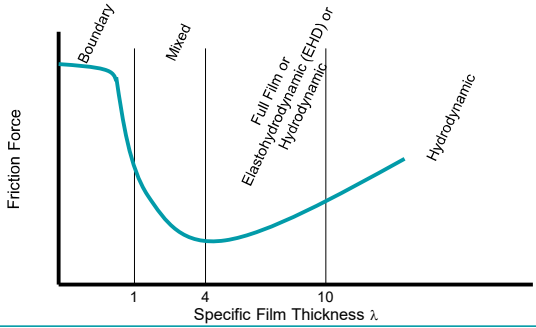
Stribeck Curve



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Lubricating Oil Properties

- Viscosity
- Viscosity Index
- Density / Specific Gravity
- Flash Point / Fire Point
- Pour Point
- Cloud Point

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Viscosity

- Measurement of the oil's internal resistance to motion.

Courtesy Imperial Oil

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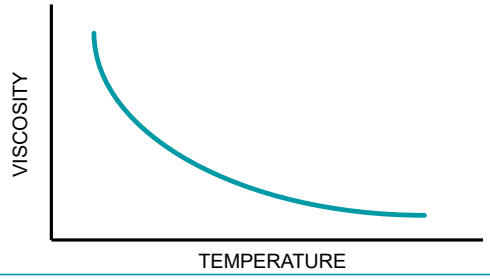
Viscosity

- As the temperature increases the viscosity will decrease.



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Viscosity

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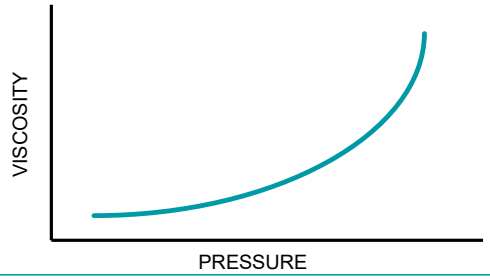

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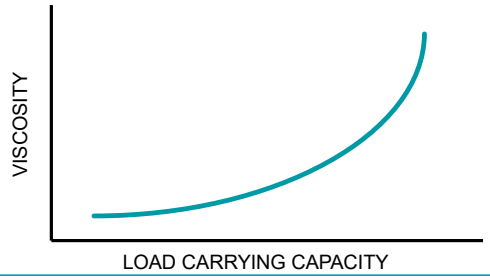
Viscosity

- Load carrying capacity increases with viscosity.



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Viscosity

- How is viscosity affected by the shear rate over time?

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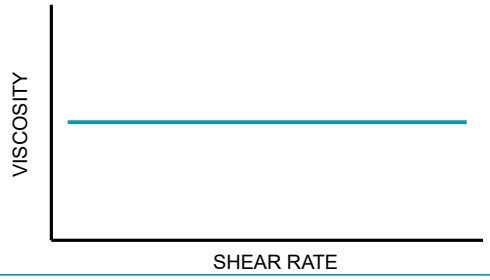
Viscosity

- Viscosity will not change with increasing shear rate in Newtonian fluids.



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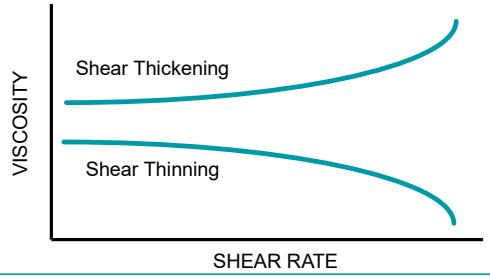
Viscosity

- Viscosity will decrease with increasing shear rate in non-Newtonian fluids.



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Viscosity

- Kinematic:
  - Measure of fluid's resistance to flow under gravity.
  - Derived from the time taken for a lubricant to travel through a capillary tube.
  - Unit of measure - Stoke (St):
    - = 1 cm^2 / second
    - Typically reported as centistoke - (cSt): = 1 mm^2 / second.
- Absolute:
  - Measure of a fluid's resistance to flow under an applied force.
  - Derived from the force required to turn a spindle submerged in a lubricant.
  - Unit of measure - Poise (P):
    - = dyne • s/cm^2 = 10μN • s/cm^2
    - Typically reported as centipoise (cP):Absolute Viscosity = Kinematic Viscosity x Density

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ISO Viscosity System

ISO VISCOSITY GRADE	MID POINT @40°C (cSt)	MINIMUM (cSt)	MAXIMUM (cSt)
2	2.2	1.98	2.42
3	3.2	2.88	3.52
5	4.6	4.14	5.06
7	6.8	6.12	7.48
10	10	9.0	11.0
15	15	13.5	16.5
22	22	19.8	24.2
32	32	28.8	35.2
46	46	41.4	50.6
68	68	61.2	74.8
100	100	90	110
150	150	135	165
220	220	198	242
320	320	288	352
460	460	414	506
680	680	612	748
1000	1000	900	1100
1500	1500	1350	1650

ISO SYSTEM
+/- 10%

EXAMPLE
ISO VG 32
Range 28.8 to 35.2 cSt @ 40°C

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SAE J300 (2013) Viscosity Classification

SAE VISCOSITY GRADE	LOW TEMPERATURE CRANKING VISCOSITY, MAX (cP @ °C)	LOW TEMPERATURE PUMPING VISCOSITY, MAX (cP @ °C)	KINEMATIC VISCOSITY @ 100°C, MIN (cSt)	KINEMATIC VISCOSITY @ 100°C, MAX (cSt)	HIGH SHEAR RATE ABSOLUTE VISCOSITY @ 150°C, MAX (cP)
0W	6200 at -35	60 000 at -40	3.8	-	-
5W	6600 at -30	60 000 at -35	3.8	-	-
10W	7000 at -25	60 000 at -30	4.1	-	-
15W	7000 at -20	60 000 at -25	5.6	-	-
20W	9500 at -15	60 000 at -20	5.6	-	-
25W	13000 at -10	60 000 at -15	9.3	-	-
16	-	-	6.9	<8.2	2.3
20	-	-	6.9	<9.3	2.6
30	-	-	9.3	<12.5	2.9
40[1]	-	-	12.5	<16.3	2.9
40[2]	-	-	12.5	<16.3	3.7
50	-	-	16.3	<21.9	3.7
60	-	-	21.9	<26.1	3.7

[1] with 0W-40, 5W-40 and 10W-40 grades [2] with 15W-40, 20W-40 and 25W-40 grades

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Why Consider 0W-30?

SAE VISCOSITY GRADE	VISCOSITY AT 40°C (cSt)	VISCOSITY AT 100 °C (cSt)
10W-30	79	12.0
5W-30	65	11.0
0W-30	69	12.2

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SAE J306 (2005) Gear Oil Classification

SAE VISCOSITY GRADE	MAXIMUM TEMPERATURE FOR VISCOSITY OF 150,000 cP (°C)	MINIMUM VISCOSITY (cSt @ 100°C)	MAXIMUM VISCOSITY (cSt @ 100°C)
70W	-55	4.1	-
75W	-40	4.1	-
80W	-26	7.0	-
85W	-12	11.0	-
80	-	7.0	<11.0
85	-	11.0	<13.5
90	-	13.5	<18.5
110	-	18.5	<24.0
140	-	24.0	<32.5
190	-	32.5	<41.0
250	-	41.0	-

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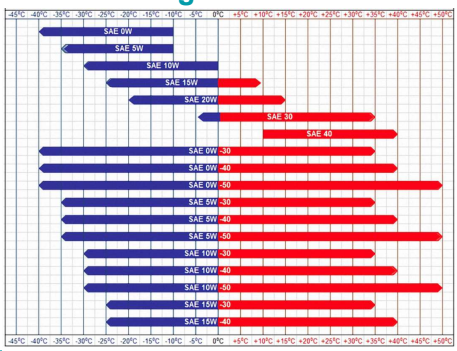
Multi-grade oil chart



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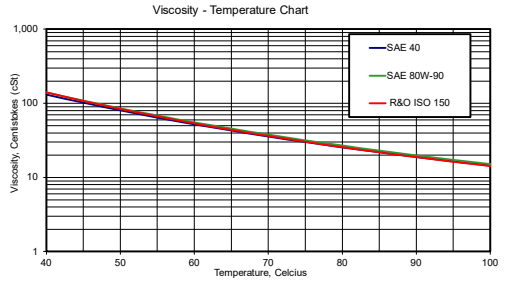
What product has the right viscosity?



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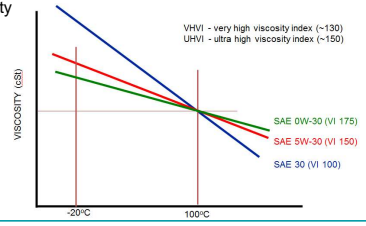
Viscosity Index

- VI is a unit less number indicating the effect of temperature on the viscosity of an oil.
- The higher the VI the less effect temperature has on the viscosity



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Consequences of Incorrect Viscosity

- Too High:
  - Poor oil flow and lubrication to bearings.
  - Increased energy consumption.
  - High temperature causes - build up of products of oxidation.
  - Inadequate defoaming / demulsifying properties.
  - Cavitation.
  - Reduced pumpability during cold starts.
- Too Low:
  - Shearing (loss of oil film) leads to high wear.
  - Insufficient lubrication at high temperatures, low speed, and / or high load.
  - Loss of energy due to friction.
  - Internal or external leakage.

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Density / Specific Gravity

- Typical specific gravity of a lube oil is in the range of 0.85-0.90, where water = 1.
- Density would be expressed as 850 kg/m^3 or 0.85 kg/l.

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Flash and Fire Point

- The flash point is the temperature at which the air vapor mixture above the surface of the oil will flash in the presence of a flame.
- The fire point is the temperature at which there is sufficient vapor to sustain combustion for 5 seconds.

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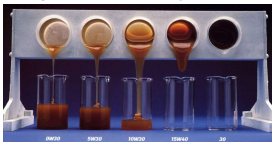
Pour Point / Cloud Point

- Pour Point
  - The temperature at which there is no movement in the oil, when tipped at 90°, for 5 seconds.
  - Influenced by wax crystallization.
- Cloud Point
  - The point, as the temperature is lowered, at which the lubricant begins to become cloudy due to the onset of wax crystallizations.



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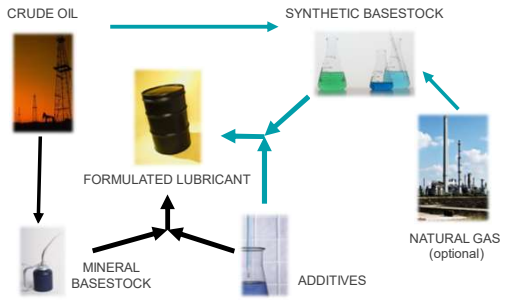
Base Oil Types



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Lube Base Oils - API Classification

BASE OIL CHARACTERISTICS					
API GROUP	sulfur WT %		SATURATES WT %	VISCOSITY INDEX	MANUFACTURING METHOD
I	> 0.03	and/or	< 90	80-119	Solvent Refined
II	< 0.03	or	> 90	80-119	Hydroprocessed
III	< 0.03	or	> 90	120 +	Severely Hydroprocessed
IV	Polyalphaolefins (PAO)		125-200+		Oligomerization
V	All other base oils not included above				Various

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Hydrotreated Oils

- Pros:
  - May use poor quality crude.
  - Lower operating costs.
  - Typically have higher VI's.
  - Improved oxidation resistance.
  - Improved high temperature stability.
- Cons:
  - Higher capital costs.
  - Requires hydrogen supply.
  - High pressure units.
  - Skilled technicians.
  - Different additive package.

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Synthetic Oils

SYNTHETIC	COMMON APPLICATIONS
Polyalphaolefins (PAO)	Most Mobile & Industrial Lubricants
Alkylbenzenes	Refrigeration Compressor
Diesters	Compressors, co-synthetic with PAO
Polyolesters (POE)	Jet Engines, Refrigeration Compressors
Polyalkylene Glycols (PAG)	Natural Gas & Refrigeration Compressors
Phosphate Esters	Fire Retardant Hydraulic Fluids
Silicones	Heat Transfer Oils

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Polyalphaolefins (PAO)

- Pros:
  - Low pour point.
  - Long oxidation life.
  - Lower volatility.
  - High Viscosity Index.
  - More energy efficient.
- Cons:
  - Limited biodegradability.
  - Cost not conducive for:
    - Once-through systems.
    - Leaking systems.

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Diesters

- Pros:
  - Long oxidation life.
  - Lower volatility.
  - High Viscosity Index.
  - Good biodegradability.
  - Examples:
    - Anderol 500 & 750
- Cons:
  - Bad hydrolytic stability.
  - Limited compatibility with seal materials and paints.

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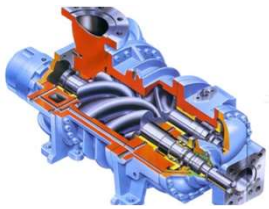
Polyglycols

- Pros:
  - High temperature, low coking tendency.
  - Examples:
    - Sullube 32
    - Ingersoll-Rand SSR
    - Summit Supra 32
- Cons:
  - Water soluble.
  - Hydrocarbon soluble.



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Phosphate Esters

- Pros:
  - Excellent thermal stability, fire resistance.
  - Good for high pressures.
  - Excellent anti-wear.
  - Examples:
    - Reolube
    - Houghton 900
- Cons:
  - Very high price.
  - Low viscosity index.
  - Limited seal material compatibility.
  - Not miscible with mineral oils.
  - May attack some metal surfaces, paints.

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Polyolesters

- Pros:
  - High temperature stability.
  - Low volatility.
  - Examples:
    - BP Turbo Oil 2380
    - Mobil Jet II
- Cons:
  - Limited compatibility with seals and paints.
  - Poor hydrolytic stability.

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Silicones

- Pros:
  - High viscosity index.
  - Low pour points, good low temperature fluidity.
  - Fire resistant.
  - Water repellent.
  - Low volatility.
  - Great oxidation stability.
  - Example:
    - Dow Corning 200
- Cons:
  - Extremely high cost.
  - Worst mixed film lubrication properties.
  - Not miscible with mineral oil and additives.
  - Forms formaldehyde gas when overheated.

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Esters

- Synthetics at risk for water-induced degradation (hydrolysis):
  - Phosphate ester
  - Polyolester
  - Dibasic acid ester

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Base Oils Comparative Characteristics

	MINERAL OIL*	POLYALPHA-OLEFIN	DIESTER	POLYOL ESTER	POLY-GLYCOL	PHOSPHATE ESTER	SILICONE OIL
VISCOSITY TEMPERATURE	Fair	Good	Good	Good	Very Good	Poor	Excellent
LOW TEMPERATURE	Poor	Good	Good	Good	Good	Fair	Good
OXIDATION STABILITY	Fair	Very Good	Good	Excellent	Good	Fair	Good
COMPATIBLE WITH MINERAL OIL	Excellent	Excellent	Good	Fair	Poor	Poor	Poor
LOW VOLATILITY	Fair	Excellent	Excellent	Excellent	Good	Good	Good
ANTI-RUST	Excellent	Excellent	Fair	Fair	Good	Fair	Good
ADDITIVE SOLUBILITY	Excellent	Good	Very Good	Very Good	Fair	Good	Poor
SEAL SWELL	Excellent	Excellent	Fair	Fair	Good	Fair	Excellent

*Characteristics vary by base oil group

Ref. Various

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Additive Types

- Active on Metal Surface:
  - Anti-wear (AW)
  - Extreme Pressure (EP)
  - Friction Modifier
  - Tackifier
  - Oxidation Inhibitor
  - Rust and Oxidation Inhibitor
  - Detergent
- **SURFACANT**
- Active in the Oil:
  - Viscosity Index Improver
  - Anti-Oxidant
  - Dispersant
  - Anti-foaming Agent
  - Demulsifier
  - Emulsifier
  - Pour Point / Cloud Point Depressant
- **PENETRATING**

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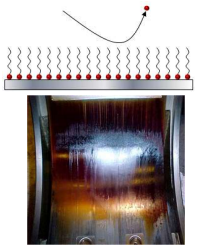
Detergents



- Role:
  - Neutralize combustion acids.
  - Inhibit deposit formation.
- How They Work:
  - Prevent deposition of sludge and varnish.
  - Neutralize strong acids due to alkali nature.
  - Form a protective film on metal surfaces.
- Common Additives:
  - Sulphonates, phenates or phosphonates of calcium and magnesium.
- Ultimate Outcome:
  - Additive is consumed:

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Dispersants

- Role:
  - Prevent agglomeration and promote suspension of polar particles:
    - Sludge, varnish, dirt, oxidation products, water
- How They Work:
  - Dispersant forms micelle around polar contaminants to hold them in solution.
- Common Additives
  - Non-metallic portion of detergent additive
  - Polyisobutylene succinimides

- Ultimate Outcome
  - Additive is consumed and can be filtered out with polar contaminant.

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Detergents versus Dispersants

DETERGENTS ATTRACTED TO METALIC SURFACES

DISPERSENTS ATTRACTED TO POPLAR CONTAMINENTS

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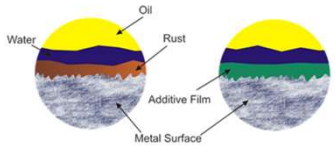
Rust and Oxidation Inhibitor

- Role:
  - Protects iron and steel parts from attack by acidic contaminants and water.
- How They Work:
  - Forms a protective film on metal to prevent attack by oxygen, water and acids.
  - Delicate balance, can interfere with other surface active additives.
- Common Additives:
  - Calcium sulphonate
- Ultimate Outcome:
  - Additive is consumed.



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Anti-Oxidant

- Role:
  - To prevent formation of oxidative products (varnish, sludge and acids).
  - Reduce copper/lead bearing corrosion.
- How They Work:
  - React with oxidation intermediate reactive products, free radicals and hydroperoxides, to stop the oxidation reaction.
- Common Additives:
  - Zinc dialkyldithiophosphate (ZDDP)
  - Hindered phenols
  - Aromatic amines
- Ultimate Outcome:
  - Additive is consumed.

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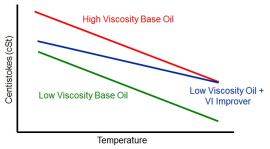
Viscosity Index Improver

- Role:
  - Reduces the rate of viscosity decreasing from increasing temperature.
  - Used to make multi-grade lubricants.
- How They Work:
  - Shrink when cold, unfurl when hot.
- Common Additives:
  - Polymethacrylates
  - Ethylene propylene copolymers
- Ultimate Outcome:
  - VI Improvers are susceptible to shear effects.
  - Permanent shear due to rupture of polymer.
  - Temporary shear thinning (aligning of polymer molecules in direction of flow).



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Anti-Foaming

- Role:
  - Prevent formation of surface foam.
- How They Work:
  - Changes surface tension of oil so that air bubbles break easily.
  - Promotes the formation of small bubbles into large ones that burst easily.
- Common Additives:
  - Dimethylsilicones (dimethylsiloxanes):
    - Very low concentrations.
- Ultimate Outcome:
  - Additive is consumed.
  - May be filtered out if bonded with polar contaminant.

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Anti-Wear (AW)

- Role:
  - Minimize metal-to-metal contact under boundary and mixed lubrication regimes:
    - For lighter loads, i.e. engines and hydraulics.
- How They Work:
  - Forms a sacrificial layer surface by **plating out** at temperatures of 65 - 100 °C.
- Common Additives:
  - Zinc dialkyldithiophosphate (ZDDP)
- Ultimate Outcome:
  - Resolubilizes for reuse, consumed from role as anti-oxidant causes light chemical wear to surface.

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Extreme Pressure (EP)

- Role:
  - Minimize metal-to-metal contact under boundary and mixed lubrication regimes:
    - For heavier loads, i.e. gear boxes.
- How They Work:
  - Forms a sacrificial layer surface by reacting with metal surface at higher temperature and pressure.
- Common Additives:
  - Dark active sulfur hydrocarbon
  - Chlorinated paraffin
- Ultimate Outcome:
  - Consumed as it reacts with water to form acids.
  - Reactive EP additives cause aggressive micro-pitting of surfaces.

57

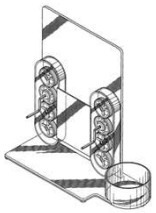
Friction Modifiers

- Role:
  - Reduce the coefficient of friction at low temperatures and mild sliding conditions.
- How They Work:
  - Polar end adsorbs to metal surface.
  - Increase oil film strength.
- Common Additives:
  - Molybdenum disulphide
  - Graphite
  - Polytetrafluoroethylene (PTFE), a.k.a. Teflon
- Ultimate Outcome:
  - Additive is consumed.

58

Tackifiers

- Role:
  - Impart a tack, or stringiness, to lubricants to provide drip resistance or inhibit stray mist in pneumatic system lubricants.
- How They Work:
  - Promotes surface adhesion.
  - Increase oil film strength.
- Common Additives:
  - Polyisobutane.
  - Co-polymers of ethylene and propylene.
- Ultimate Outcome:
  - Additive is oxidized.

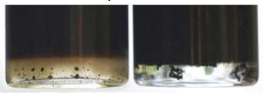


Lucas Oil demonstrator

59

Demulsifer

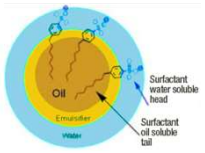
- Role:
  - Promote oil-water separation for lubricants exposed to water or steam.
- How They Work:
  - Surface-active agent (surfactant) that release moisture from the lubricant.
- Common Additives:
  - Polyisobutane
- Ultimate Outcome:
  - Exposure to water causes depletion.



60

Emulsifier

- Role:
  - Promote stable mixture or emulsion.
- How They Work:
  - Polar molecule that is water-soluble at one end and oil-soluble at the other.
  - Reduce surface tension to facilitate mixing.
- Common Additives:
  - Co-polymers of ethylene and propylene.
- Ultimate Outcome:
  - Limited capacity unless water is driven off.



61

Pour / Cloud Point Depressant

- Role:
  - Enhances the lower operability temperature of the oil.
- How They Work:
  - Inhibit the formation and agglomeration of wax crystals.
- Common Additives:
  - Co-polymers of polyalkyl methacrylates.
- Ultimate Outcome:
  - Additive is consumed.

62

Additives

- Loss of Additives
  - Most additives physically or chemically decompose in service.
  - Additives will break down by:
    - Hydrolysis
    - Oxidation
    - Thermal Degradation
    - Shear down
- Additive Concentration
  - There is no way to replenish additives, other than to add more.
  - No mechanism to “regenerate” or “fix” additives.
  - No OEM or lubricant supplier endorses the use of aftermarket additives in fully-formulated products:
    - A fully-formulated oil, will balance the surface acting additives so that all will perform as expected.
    - The addition of a supplemental additive package may impact this balance.

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Additive Concentrations

COMPONENT TYPE	COMMON ADDITIVES	CONCENTRATION (BY VOLUME)
Engines	Detergents, oxidation inhibitor, corrosion inhibitor, anti-wear (AW), anti-foam, viscosity index improver, alkalinity improver	10 - 30%
Gears (spiral, bevel or hypoid)	Anti-wear (AW), oxidation inhibitor, anti-foam, sometimes corrosion inhibitor, extreme pressure (EP)	1 - 10%
Hydraulics	Oxidation inhibitor, anti-wear (AW), anti-foam, corrosion inhibitor, pour-point depressant, viscosity index improver	2 - 10%
Gears (worm)	Extreme pressure (EP), oxidation inhibitor, corrosion inhibitor, friction modifier	3 - 10%
Steam turbines, Compressors	Rust inhibitor & oxidation inhibitor (R&O), demulsifier, anti-foam	0.1 - 5%

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Agenda

- **Fundamentals of Lubricants**
  - Lubricant Functions
  - Lubricating Oil Films
  - Oil Properties
  - Base Oil Types
  - The Functions of Lubricant Additives
  - **Grease Properties**
- Contamination Sources and Control Strategies
- Oil Sampling Basics
- Sample Registration
- Data Interpretation

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Grease

- A solid to semi-fluid product made up of a liquid lubricant and a thickening agent.
- The nature and properties of the thickener, and the characteristics of the liquid lubricant, determine the properties of a grease.
- Two basic thickener types:
  - Soap
  - Non-soap
- Thickener Determines finished characteristics:
  - Temperature range
  - Pumpability
  - Water resistance
  - Stability - mechanical

66

Grease

- Why use grease?
  - Decrease dripping, splattering and leakage.
  - Seal out contaminants.
  - Do not need circulation systems.
  - Suspend solid additives easily.
  - Suitable for intermittent operations.
  - Work under extreme operating conditions.
  - Some bearings can be pre-lubricated at factory and even sealed for life.
  - Reduce noise.
  - Greased machinery tends to need less power.
- Why not use grease?
  - May not reach all places in need of lubrication.
  - Does not have any cleaning effect.
  - Does not work as cooling agent.
  - Cannot be used at as high speeds as liquids.
  - Easy to over/under lubricate without proper procedures followed.

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Factors Affecting Grease Quality

- Additives - 1-10%:
  - Enhance base oil performance.
- Thickener - 5-20%:
  - Holds it all together and enhances properties of the oil.
- Base Oil - 70-90%:
  - Natural or Synthetic.
  - Provides the main lubrication function.

Courtesy of Noria

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Base Oil Viscosity for Grease

VISCOSITY	APPLICATION
ISO 100 & lower	Used for high speeds >3600 rpm, lower loads, good at low temperatures
ISO 150/220	Moderate speeds up to 3600 rpm, good load carrying, typical multi-purpose grease's oil
ISO 460	Higher loads than ISO150/220, often with improved water resistance
ISO 1500	Typical speeds <100 rpm, excellent load carrying, good water resistance

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Basic Properties

THICKENER	MAX. SERVICE TEMP °C	SHEAR STABILITY	WATER RESISTANCE	DROPPING POINT °C
Sodium Soap	93 -136	Med - Good	Poor	170-200
Calcium Soap				
Simple	121	Good	Good	80-100
Complex	149	Medium	Good	260+
Lithium				
Simple	163	Good	Medium	175-205
Complex	177	Good	Med - Good	260+
Aluminum				
Simple	79	Poor	Good	110
Complex	149	Medium	Good	260+
Clay	177	Medium	Medium	260+
Polyurea	177	Med - Good	Good	260+

Without performance enhancing additives

Ref: Various

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GREASE COMPATIBILITY GUIDELINES

FLUID LIFE EQUIPMENT RELIABILITY SERVICES

	Aluminum Complex	Barium	Calcium	Calcium 12-hydroxystearic Acid	Calcium Complex	Clay	Lithium	Lithium 12-hydroxystearic Acid	Lithium Complex	Polyurea	Sodium	Calcium Sulphonate	Silica
Aluminum Complex	○	×	×	●	×	×	×	×	●	×	×	×	●
Barium	×	○	×	●	×	×	×	×	×	×	×	□	●
Calcium	×	×	○	●	×	●	●	□	●	×	×	N/A	N/A
Calcium 12-hydroxystearic Acid	●	●	●	○	□	●	●	●	●	×	×	N/A	N/A
Calcium Complex	×	×	×	□	○	×	×	×	●	●	×	●	×
Clay	×	×	●	●	×	○	×	×	×	×	×	×	●
Lithium	×	×	●	●	×	×	○	●	●	×	×	●	●
Lithium 12-hydroxystearic Acid	×	×	□	●	×	×	●	○	●	×	×	●	N/A
Lithium Complex	●	×	●	●	●	×	●	●	○	×	×	●	●
Polyurea	×	×	×	×	●	×	×	×	×	○	×	×	×
Sodium	×	×	×	×	×	×	×	×	×	×	○	×	×
Calcium Sulphonate	×	□	N/A	N/A	●	×	●	●	●	×	×	○	N/A
Silica	●	●	N/A	N/A	×	●	●	N/A	●	×	×	N/A	○

○ Same Grease
● Compatible
× Not Compatible
□ Moderately Compatible

○ NOTE: Not all polyurea greases are mutually compatible
Contact Fluid Life for more information (info@fluidlife.com or 877-962-2400)

Ref: ALGI (Lubesmart, https://www.machinerylubrication.com/Read/28937/understanding-grease-compatibility

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Agenda

- Fundamentals of Lubricants
- **Contamination Sources and Control Strategies**
  - **Overview**
  - Contamination Sources
  - Contamination Control Strategies
  - Filtration
- Oil Sampling Basics
- Sample Registration
- Data Interpretation

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Why Machines Fail

- They become obsolete.
- They degrade.
- Accidents/Incidents.

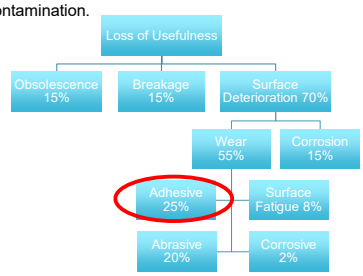
Loss of usefulness

- Due to:
  - Corrosion (water, acid due to oxidation).
  - Mechanical Wear (particles):
    - Adhesive
    - Abrasive
    - Erosive
    - Fatigue Wear

73

Why Machines Fail

- Most failures are attributable to some form of particulate contamination.



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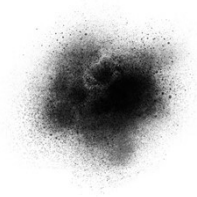
What is Contamination?

- Contaminate - to make unfit for use by the introduction of unwholesome or undesirable elements:
  - External contamination/Ingestion:
    - Dirt, dust, etc.
    - Water
  - Self-generated contamination:
    - Built-in/Break-in
    - Wear particles
  - Chemical contamination/Generated:
    - Mixing of lubricants
    - Additives



75

New equipment is NOT clean

- A system is **considered clean when foreign matter**, such as scale, rust, metal shavings and sand, are not visible to the eye and grittiness is **not detectable to the touch**.

76

New oil cleanliness is poor

- New oil can be much dirtier than what an OEM recommends.
- This is especially important in equipment that requires critical cleanliness such as:
  - Hydraulics
  - Large Turbines
  - Etc.

77

How Clean Do We Need?

- The critical particle size that must be controlled is typically 1 to 5 microns to maximize component life.
  - Lubrication Engineering, February 1997
- Controlling the abrasive contaminants in the range of 2 to 22 µm in the lube oil is necessary for controlling engine wear.
  - Staley, David R. “Correlating Lube Oil Filtration Efficiencies with Engine Wear,” SAE 881825

78

Typical Dynamic Clearances

Component	Details	Clearances
Valves	Servo	1 - 4 µm
	Proportional	1 - 6 µm
	Directional	2 - 8 µm
Variable Volume Piston Pumps	Piston to Bore	5 - 40 µm
	Valve Plate to Cylinder block	0.5 - 5 µm
Vane Pumps	Tip to Case	0.5 - 1 µm
	Sides to Case	5 - 13 µm
Gear Pumps	Tooth Tip to Case	0.5 - 5 µm
	Tooth to Side Plate	0.5 - 5 µm
Ball Bearings	Film Thickness	0.1 - 0.7 µm
Roller Bearings	Film Thickness	0.1 - 1 µm
Journal Bearings	Film Thickness	0.5 - 100 µm
Seals	Seal and Shaft	0.05 – 0.5 µm
Gears	Mating Faces	0.1- 1 µm

Ref. ASME (American Society of Mechanical Engineers) Wear Handbook

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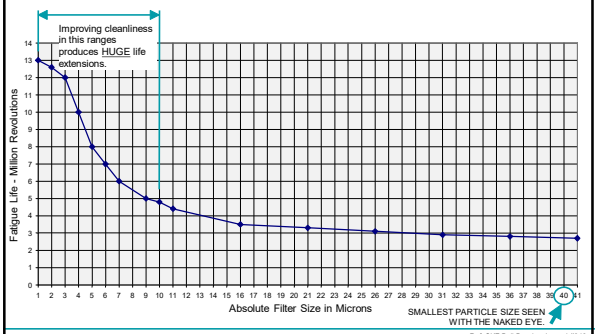
Bearing Life vs. Particle Size



Ref: SKF Ball Bearing Journal #242

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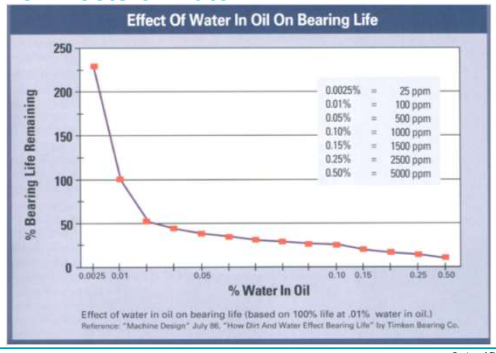
The Effects of Water….

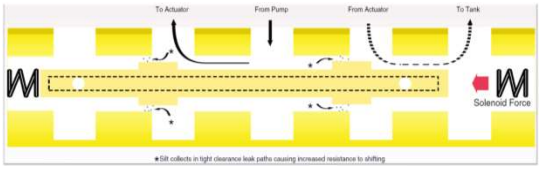


Courtesy of: Timken Bearing

81

Size, Not Quantitiy

- Valve Stiction or Silt Lock:
  - Contaminants can jam servo, proportional, and directional valves.
  - Sluggishness, jamming, and instability can result due to contamination from a single clearance-sized particle.



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Agenda

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Contamination Sources

- Self-generated contamination.
- External contamination.
- Built-in/Break-in contamination.

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Contamination Sources

- **Self-Generated:**
  - Metallic wear
  - Seal abrasion
  - Chemical corrosion
  - Oxidation residue
  - Oil-insoluble substance caused by mixing oil.

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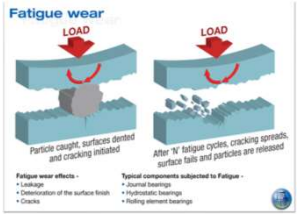
Metallic Wear - Adhesive

Courtesy Pall Corporation

86

Metallic Wear - Fatigue



Courtesy Pall Corporation

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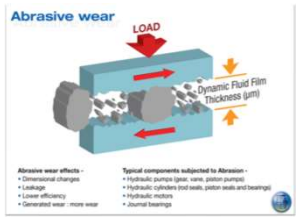
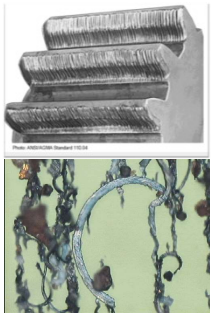
Metallic Wear - Abrasive

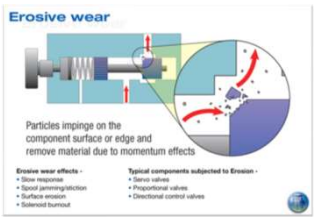


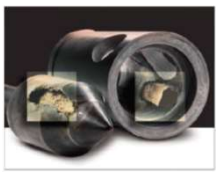


Courtesy Pall Corporation

88

Metallic Wear - Erosive





Courtesy Pall Corporation

89

Seal Abrasion

90

Chemical Corrosion

91

Oxidation Residue

92

Mixing Oil

Courtesy: Clarus Technologies

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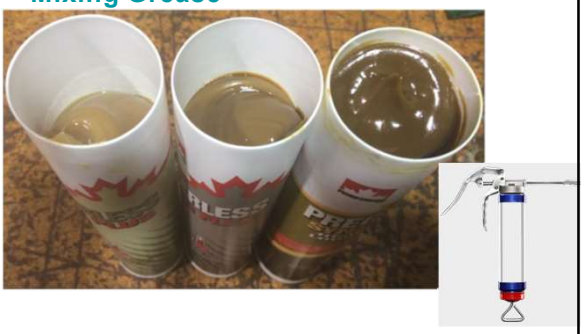
Mixing Grease



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Mixing Oil or Grease?

95

Contamination Sources

- **External Contamination:**
  - Airborne contaminants
  - Contamination caused by adding oil
  - Contamination by adding grease
  - Water Ingress

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Airborne Contaminants

- Examples of air contaminants that only became visible with the camera flash.

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Airborne Contaminants

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Airborne Contaminants

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Contamination caused by adding oil

- Did the rag do its job and keep the container clean?

100

Contamination caused by adding oil

101

Contamination caused by adding grease

102

Contamination Sources - Water

- Water will affect an oil's viscosity:
  - Free → **Increases** viscosity (visible)
  - Emulsified → **Increases** viscosity (cloudy in water)
  - Dissolved → **Decreases** viscosity water is dissolved and invisible in oil).
- As an oil ages (oxidizes), it can hold more water.

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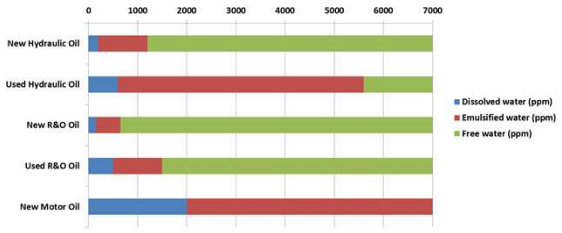
Contamination Sources - Water

- The higher the additive package, the more water an oil will hold.



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Contamination Sources

- **Built-in / Break-in Contamination:**
  - Foundry sand, dust.
  - Manufacturing residue:
    - Welding residue
    - Metals swarf (turnings, filings, shavings, etc…)
    - Blasting material, lacquer/paint particles
    - Preservation material
    - New parts install
  - Residue from cleaning agents (rag fibers).
  - New part installation or equipment repair/overhauls.

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Contamination Control Strategies

1. Lubricant receiving procedures.
2. Storage and inventory management.
3. Lubricant Handling.
4. Exclusion of Contaminants.
5. Health and safety assurance.

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Lubricant Receiving Procedures

- **Step 1:**
  - Determine an acceptable and manageable cleanliness level for stored fluids.
  - Begin with understanding the cleanliness of oils being delivered on site.
  - New oils average an ISO code of 20/19/16 cleanliness or higher which is up to eight times dirtier than recommended for a majority of critical machinery.

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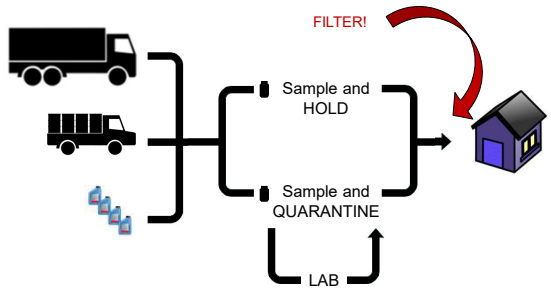
Lubricant Receiving Procedures



109

Lubricant Receiving Procedures

- Quality Control:
  - Sampling new oil can verify the following:
    - Quality of base stock
    - Additive quality and concentrations (+/- 25% variance ok)
    - Lubricant performance properties.
    - Grease thickener performance properties.
  - Important information to document and track:
    - Delivery date, and date of oil sample.
    - Storage container inspection details:
      - Check for damaged containers, broken or damaged seals.
    - Labels with results of oil analysis (eg. Cleanliness).
    - Periodic filtration of bulk storage and drums.

110

Storage and Inventory Management

- **Step 2:**
  - Take measures to exclude contaminants from becoming part of the lubricant or fluid.
  - This must happen in the main stores and at the individual storage stations throughout your plant.

111

Storage and Inventory Management

- Bulk Oil Storage:
  - Typically 10,000 gallon tank or 55 gallon drums.
  - Need to avoid contamination and additive settling.
  - Optimize bulk storage by:
    - Determining lubricant consumption rate.
    - Determining lubricant storage capacity.
    - Determining lubricant supplier turnaround time.
    - Identifying lubricant requirements for critical equipment.

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Storage and Inventory Management

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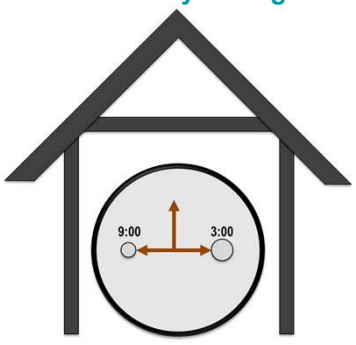
Storage and Inventory Management



114

Storage and Inventory Management

- Lubricant Room Design:
  - Location
  - Cleanliness
  - Worker Safety
  - Lubricant contamination control
  - Lubricant filling control
  - Procedures and staging area for new lubricants.
  - Ability to document actions (record keeping).
  - Optimize bulk oil and grease volumes.
  - Limited access door, with a record of people who enter.
  - Fire proof storage for top up containers, grease guns, etc.
  - Separate storage area to store bulk totes, drums, buckets, etc.

115

Great Lube Rooms

116

Storage of Grease and Top-up Containers

- Each should have a dedicated fire proof cabinet.
- Clean, dry, and cool.
- Grease guns should be cleaned periodically, and calibrated annually (ensure the same volume of grease is delivered per pump).
- If grease drums are used to fill grease guns, they must be resealed carefully.

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Lubricant Handling - Oil

- **Step 3:**
  - Preserving the integrity of the fluid while getting it from storage to usage.
  - Bear in mind that often the best ways are also the easiest and most efficient ways.

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Lubricants Handling - Oil

- Top up/small oil change out containers.

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Lubricant Handling - Oil

- Topping up from drums and bulk storage:
  - Best practice is to filter the dispensing oil (again).
  - Can use a hard plumbed filtration system with dedicated dispensing nozzles on a rack mounted system.
  - 55-gallon drums can be fitted with quick connect fittings, a hand pump, sight glass, and breather (with filter).
  - Filtered hand pumps with breathers

Courtesy Lubrication Engineers

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Storage and Inventory Management

- Containers that reduce the potential of contamination:
  - Funnels represent the "highest risk factor" for contamination ingress while adding oil into components.
- Don't be afraid to go one step better:
  - Consider retro-fitting containers with air breathers, and hand pumps with quick couplers.

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Lubricant Handling - Oil

- Establish a procedure that incorporates adding oil via a portable filtration system - for larger reservoirs, etc.
- Filter Carts are good for:
  - Oil Flushing
  - Oil Addition
  - Oil Drains
  - Kidney Loop Filtration

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Lubricant Handling - Grease

- Grease guns are handled improperly:
  - Transparent or color coded greasing tools eliminate mixing products from picking up the wrong grease based on grease color.

Courtesy Lubrication Engineers

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Exclusion of Contaminants

- **Step 4:**
  - The cost of cleaning dirty oil can be 10X higher than keeping it clean in the first place.
  - High-quality breathers can exclude particles as small as ½ micron.
  - Desiccant breathers will also exclude moisture.

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Health and Safety Assurance

- **Step 5:**
  - Oil can be HOT and slippery.
  - Keeping your lubrication storage clean, cool, and dry will also safeguard against slips, trips, burns, and other safety incidents.
  - Machines that are properly lubricated are also less likely to fail, and therefore safer to be around.
  - If a skin condition develops after handling lubricants:
    - Consult MSDS for the product and seek medical assistance.
    - Container labels must identify hazard information. Otherwise, employers must provide the MSDS and/or appropriate training.

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Goal of Filtration

- Improve oil dryness and cleanliness.
- Help optimize the oil's usefulness.
- Improve reliability and productivity of the machine.
- Pay for itself in a short amount of time.

Courtesy CC Jensen

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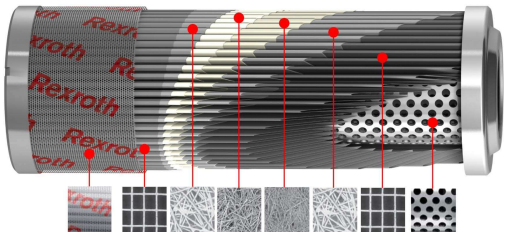
Filter Overview



1-Perforated protective cage, 2-Media support, 3-Media protection, 4-Pre-filter, 5-Main filter, 6-Protective membrane, 7-Media support, 8-Perforated center tube

Courtesy Bosch Rexroth

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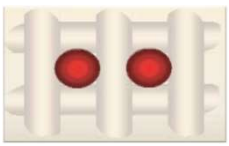
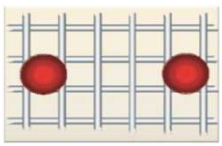
Filter Media Type

- Cellulose (Paper):
  - Lower density
  - Larger pores
  - Higher restriction
  - Random matrix
- Glass (Synthetic):
  - Higher density
  - Smaller pores
  - Lower restriction
  - Can be tapered





Courtesy CC Jensen

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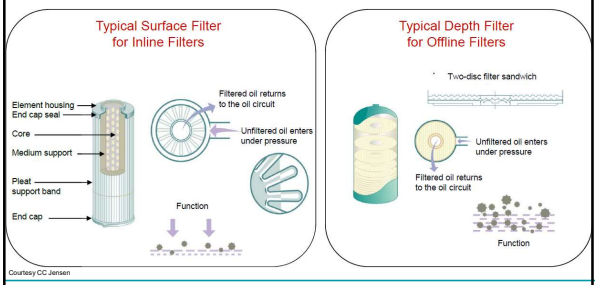
Filter Types

Surface Filtration | Depth Filtration

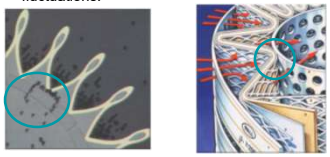


Courtesy CC Jensen

130

Filter Construction

- You can have the best media, but without the appropriate construction, particles will flow through:
  - Note the break in the pleats.
- Properly engineered construction will provide the particle-removing capability:
  - Note the media support that is resilient against pressure fluctuations.



Courtesy Pall Corporation

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Beta Ratio / Efficiency

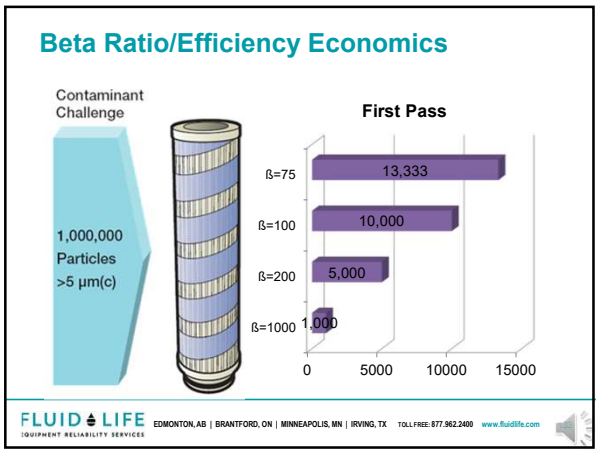
Beta Ratio	Efficiency
1	0%
2	50%
5	80%
10	90%
20	95%
75	98.7%
100	99%
200	99.5%
1000	99.9%

$ß_x = 75$

Simple calculation:

$$\frac{75-1}{75} = 98.7\%$$

132


Beta Ratio/Efficiency Economics
Contaminant Challenge
1,000,000 Particles >5 µm(c)
First Pass
ß=75
ß=100
ß=200
ß=1000
13,333
10,000
5,000
1,000
0
5000
10000
15000
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TOLL FREE: 877.962.2400
www.fluidlife.com

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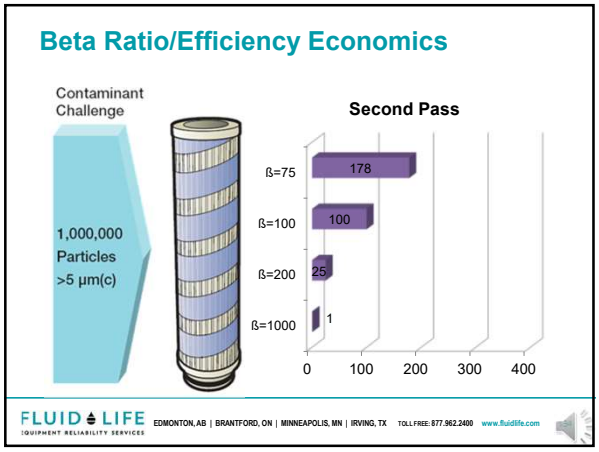
Beta Ratio/Efficiency Economics
Contaminant Challenge
1,000,000 Particles >5 µm(c)
Second Pass
ß=75
ß=100
ß=200
ß=1000
178
100
25
1
0
100
200
300
400
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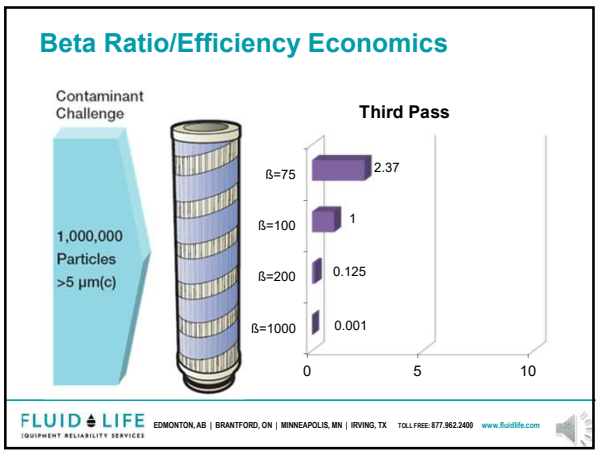
Beta Ratio/Efficiency Economics
Contaminant Challenge
1,000,000 Particles >5 µm(c)
Third Pass
ß=75
ß=100
ß=200
ß=1000
2.37
1
0.125
0.001
0
5
10
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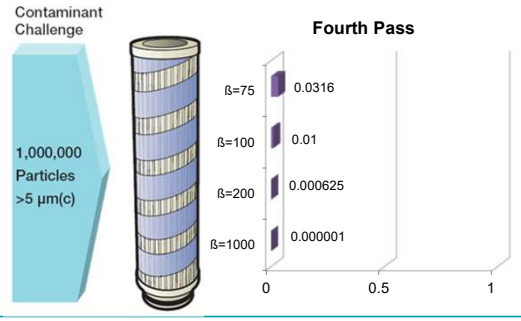
Beta Ratio/Efficiency Economics



136

Beta Ratio/Efficiency Economics

- Is a $ß_5 = 1000$ worth twice as much as a $ß_5 = 200$ filter?
- How about compared to a $ß_5 = 100$ or $ß_5 = 75$?
- In a single pass application, such as transferring to or from lubricant storage, the difference can be significant.
- In a multi-pass application, such as full-flow or kidney loop filtration, the difference becomes negligible quite quickly.

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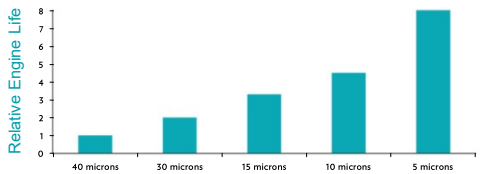
Filter Selection



- "Abrasive engine wear can be substantially reduced with an increase in filter single pass efficiency. Compared to a 40 µm filter, engine wear was reduced by 50% with 30 µm filtration. Likewise, wear was reduced by 70% with 15 µm filtration."

138

Potential Filter Problems

- Excessive Back-Pressure

- Electrostatic Discharge

139

Moisture Removal by Filtration

TECHNOLOGY	EFFICIENCY	TYPES OF WATER REMOVED
Centrifugal	Centrifuge spins out water and other higher density contaminants	Free water
Coalescing	Variable density media forces agglomeration of water to the point it separates and falls out of suspension	Free water, emulsified water
Desiccant	Water is absorbed by media, requiring filter changes	Free water, emulsified water
Head Space Air Dryer	Dry's air in the head space by pushing dry air into the headspace. And water is evacuated through desiccant breather.	Free water, emulsified water and dissolved water
Vacuum Dehydration	Oil is heated and put under a vacuum to reduce boiling point and drive out moisture in the form of steam	Free water, emulsified water and dissolved water

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Agenda

- Fundamentals of Lubricants
- Contamination Sources and Control Strategies
- **Oil Sampling Basics**
  - **Lube Oil Sampling Objectives**
  - Sampling Frequency and Location
  - Proper Sampling Methods
  - Managing Interference When Sampling
- Sample Registration
- Data Interpretation

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Lube Oil Sampling Objectives

- Samples are best taken when system is **live and/or hot.**
- Wipe the sample port before opening:
  - Don't place plugs or caps on dirty surfaces.
- Pre-label or label bottles immediately after filling to avoid mix-ups.
- Flush sample point and associated piping or tubing thoroughly.
- **"REPRESENTATIVE SAMPLE"**

Bad Routine Samples

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Lube Oil Sampling Objectives

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- **Oil Sampling Basics**
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Where, When, How Often?

- Number of samples and points depends on program's goals:
  - Monitoring filtration performance.
  - Failure diagnosis.
  - Contamination ingression.
  - Oil Change intervals.

145

Sampling Valve Installation Practices

- Install valves on elbows, rather than straight sections of pipe.
- More likely to "catch" particles at the elbow because of oil turbulence.
- A viscous fluid running through a straight line for a period can go laminar, and allow contaminants to drop out.

146

Oil Sampling Location General Guidelines

MOBILE EQUIPMENT	GOOD	BETTER	BEST
Engine	LOCATION: Oil Dipstick	LOCATION: Drain Plug	LOCATION: Sample Valve (upstream of filter)
	TOOLS: Suction pump, Plastic Tubing, Flush Jar	TOOLS: None	TOOLS: Pushbutton Sample Valve
Engine Coolant system	LOCATION: Overflow tank	LOCATION: Radiator Cap	LOCATION: Sample Valve (upstream of filter)
	TOOLS: Suction Pump, Plastic Tubing, Flush Jar	TOOLS: Suction Pump, Plastic Tubing, Flush Jar	TOOLS: Pushbutton Sample Valve
Transmission	LOCATION: Drain Plug	LOCATION: Oil Dipstick	LOCATION: Sample Valve (upstream of filter)
	TOOLS: None	TOOLS: Suction Pump, Plastic Tubing, Flush Jar	TOOLS: Pushbutton Sample Valve
Hydraulic / Steering	LOCATION: Oil Tank (Drain)	LOCATION: Oil Tank (Air Breather or Hatch)	LOCATION: Sample Valve (Return line on valve block)
	TOOLS: None	TOOLS: Suction Pump, Plastic Tubing, Flush Jar	TOOLS: Minimess Sample Valve, High Pressure Port Adaptor
Differential	LOCATION: Drain Plug	LOCATION: Oil Fill / Air Breather Plug	N/A
	TOOLS: None	TOOLS: Suction Pump, Plastic Tubing, Flush Jar	
Final Drive / Wheel Hub Spindles	LOCATION: Drain Plug	LOCATION: Oil Fill Plug (if equipped)	N/A
	TOOLS: None	TOOLS: Suction Pump, Plastic Tubing, Flush Jar	

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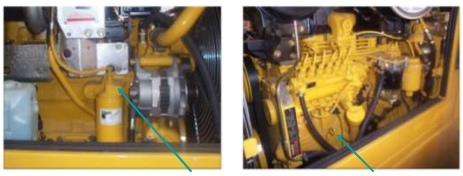
Oil Sampling Location General Guidelines

FIXED EQUIPMENT	GOOD	BETTER	BEST
Hydraulics	LOCATION: Oil Tank (Drain)	LOCATION: Oil Tank (Air Breather or Hatch)	LOCATION: Sample Valve (Return line on valve block)
	TOOLS: None	TOOLS: Suction Pump, Plastic Tubing, Flush Jar	TOOLS: Minimess Sample Valve, High Pressure Port Adaptor
Electric Motor	LOCATION: Drain valve	LOCATION: On a designated sample port	N/A
	TOOLS: None	TOOLS: Minimess Sample Valve, High Pressure Port Adaptor	
Turbines/Compressors	LOCATION: Oil Tank (Drain)	LOCATION: Oil Tank (Air Breather or Hatch)	LOCATION: Sample Valve (Return line on valve block)
	TOOLS: None	TOOLS: Suction Pump, Plastic Tubing, Flush Jar	TOOLS: Minimess Sample Valve, High Pressure Port Adaptor
Bearings	LOCATION: Drain valve	LOCATION: On a designated sample port	N/A
	TOOLS: None	TOOLS: Minimess Sample Valve, High Pressure Port Adaptor	
Gearboxes	LOCATION: Drain Valve	LOCATION: Drain port with a pitot tube above sludge line	LOCATION: On a designated sample port
	TOOLS: None	TOOLS: Minimess Sample Valve, High Pressure Port Adaptor	TOOLS: Minimess Sample Valve, High Pressure Port Adaptor
Pumps	LOCATION: Drain Valve	LOCATION: Modified Breather	N/A
	TOOLS: None	TOOLS: Suction Pump, Plastic Tubing, Flush Jar	
Stationary Engines/Generators	LOCATION: Oil Dipstick	LOCATION: Drain Plug	LOCATION: Sample Valve (upstream of filter)
	TOOLS: Suction pump, Plastic Tubing, Flush Jar	TOOLS: None	TOOLS: Pushbutton Sample Valve

148

Sample Point Identification Engines

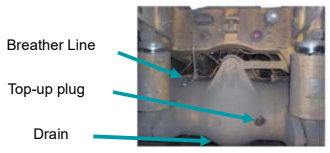
- Samples taken from installed ports (after pump, before filters) provide best sample.
- Dipstick or mid-stream drain samples can also be used.



149

Sample Point Identification Differential

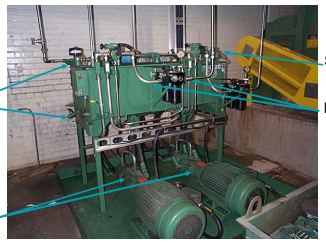
- Oil is not normally changed when sample is taken, therefore, a mid-stream drain sample is impractical for majority of samples.
- Take sample consistently from breather or top-up plug using a pitot tube if possible to take samples from consistent depth.



150

Sample Point Circulating Systems

- Samples are best taken after a pump, and before a filter.
- When trying to monitor specific components it is possible to have multiple secondary sampling points as shown below.

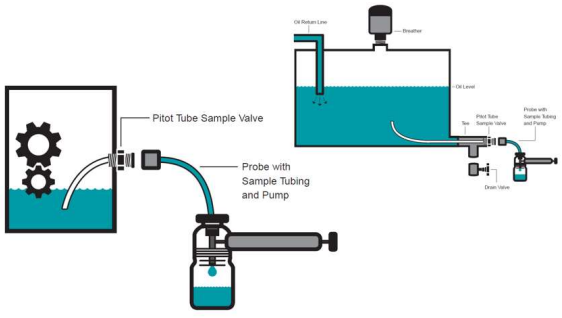


151

Sample Point Identification Gearbox

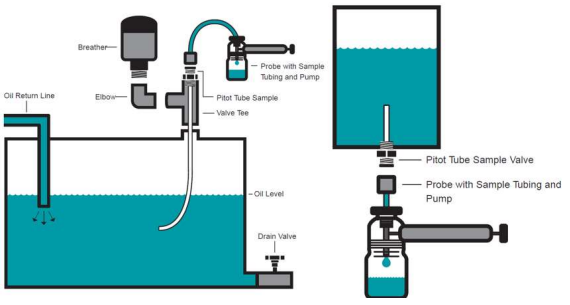
152

Sampling on a non pressurized system



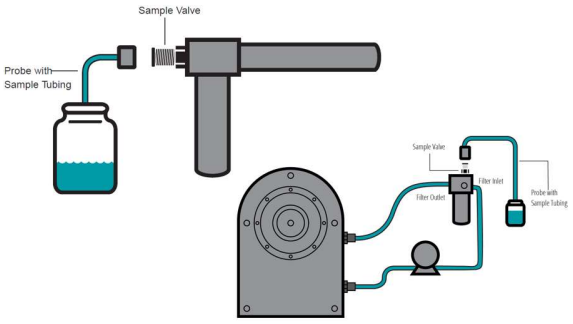
153

Sampling on a non pressurized system



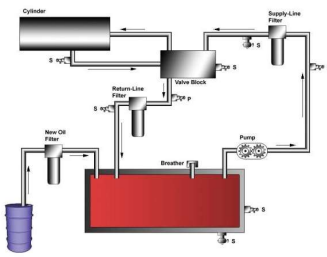
154

Sampling on a pressurized system



155

Sample Point: Hydraulics



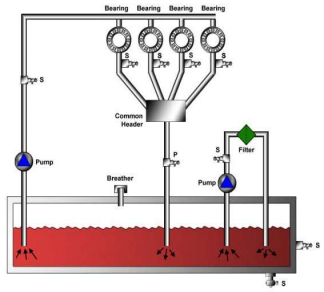
Primary sample point should be on return line, before filters or downstream of pump, upstream of filter

Secondary samples can be installed:

- Before/after supply filter
- After cylinder(s)
- On valve block
- Mid-point of reservoir

156

Sample Point: Lube Systems



Primary sample point should be installed on return line header.

Secondary sample points can be installed:

- After each bearing
- After the main pump
- Before auxiliary filter
- After auxiliary filter
- Mid-point of reservoir

157

Sample Frequency

- General guidelines are a starting point.
- Frequency of sample depends on several factors:
  - LETS (Load, Environment, Temperature, Speed)
  - Downtime costs
  - Repair / replacement costs
  - Safety requirement
  - Equipment tolerance
  - Contamination factor

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Sample Frequency

Component	Frequency
Diesel Engines	20,000 km / 250 Hrs. / Monthly
Gasoline Engines	10,000 km / Quarterly
Natural Gas Engines	500 Hrs. / Monthly
Standby Generators	50 Hrs. / Quarterly
Hydraulics	500 Hrs. / Monthly
Gears (Industrial)	750 Hrs. / Monthly
Air/Gas Compressors	500 Hrs. / Monthly
Refrigeration Compressors	Quarterly
Gas Turbines	500 Hrs. / Monthly
Steam Turbines	1500 Hrs. / Quarterly

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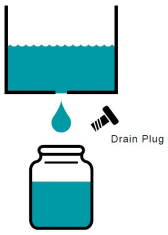
Proper Sampling Methods

- A common method of sampling is midstream from a reservoir into a sample cup.



161

Sampling Tools: Suction Pumps

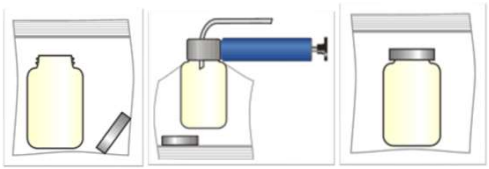
- Used on low or non-pressurized systems:
  - Gearboxes, Bearings
  - Fluid reservoirs, Return lines
- Use a new section of hose every time
- Flush tubing before every sample

1. Tubing Inlet
2. Internal Threads & Tube Canal
3. Head
4. Sample Jar (38mm)
5. Plunger Body
6. End Cap
7. Plunger

162

Sampling Tools: Suction Pump

- If Sampling in an extremely dirty environment, put sample jar in a plastic baggy.
  - Seal bottles in a bag in a clean environment
  - Screw into pump, tube will pierce bag
  - Afterwards, seal bottle without opening the bag



163

Sampling Valves: Pressurized Systems

- "B" Series Valve
- Push button valve

Courtesy Checkfluid

164

Sampling Valves: Low Pressure

- Works with a suction pump.
- "M" Series Valve
- Pitot Tube
- Modified Breather kit

Courtesy Check Fluid, Trico

165

Sampling Valves: Other Common types

- KST - Pressurized System
- Probalyzer - Pressurized System
- Cover plate - Non Pressurized System

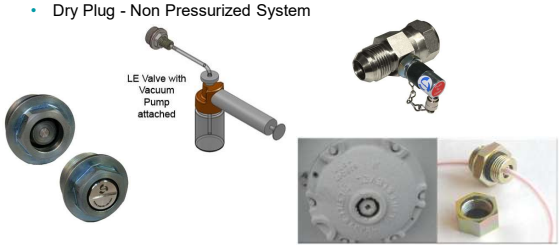


Courtesy Checkfluid, Baldwin Filters, JLM Systems

166

Sampling Valves: Other Uncommon Types

- Inline T adapter - Pressurized and Non Pressurized System
- Flush mount drain - Non Pressurized system
- Dry Plug - Non Pressurized System



Courtesy Checkfluid, JLM Systems

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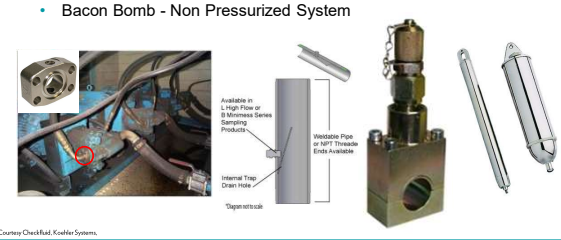
Sampling Valves: Other Uncommon Types

- Spacer Flange - Pressurized System
- Catch Pipe - Non Pressurized System
- Valve Mount - Pressurized And Non Pressurized System
- Bacon Bomb - Non Pressurized System



Courtesy Checkfluid, Koehler Systems,

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Bottle Cleanliness and Management

- Re-using any container is WRONG!
  - Examples of actual containers sent to Fluid Life.

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Bottle Cleanliness and Management

- New sample bottle cleanliness may have an affect on the oil analysis results.
- Just like new oil - all sample bottles come in varying degrees of cleanliness (dirtiness).
- Storing samples before shipping or lab analysis:
  - Samples should be shipped to Fluid Life ASAP after being taken.
  - Fluid Life labs will follow best practices and suspend solids, water, wear metals, etc. by shaking gently (end over end rolling or on a gentle shaker table) at room temperature.

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Bottle Cleanliness May Produce Bias

- Affected:
  - ISO Particle Count
  - OPC
  - Sediment (less likely)
- Not Affected:
  - Viscosity
  - Wear Metals
  - Acid Number
  - Base Number
  - Water

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Flushing

- One Sample - One Tube:
  - Never re-use a sample tube, even for the same location.
- FLUSH at least 5 to 10 times the dead space volume:
  - New tubing volume
  - Dead-legs
  - Sampling ports, valves, and probes
  - Adapters for using vacuum pumps
  - Plastic tubing

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Agenda

- Fundamentals of Lubricants
- Contamination Sources and Control Strategies
- Oil Sampling Basics
- **Sample Registration**
  - **Overview of Registering Samples**
  - Mobile App
  - Web Based
  - Sample Card
- Data Interpretation

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Importance of Sample Registration

- An incorrectly registered sample is just as bad as an improperly taken sample:
  - Label bottles immediately after filling to avoid mix-ups or pre-print labels.
  - If not logging in samples through myLab or the mobile app:
    - Ensure to always label the unit ID consistently so that the sample results don't end up in different places by us creating double units.
    - If no unit/component is listed the samples will be held and you will be contacted to ensure it's registered correctly, resulting in delayed results.
- Ensure all sample data is accurately entered:
  - Missing data will delay processing.
  - Incorrect data will give irregularities or false positives.
  - Wrong sample entry will cause incorrect data trending.
  - Registering Samples correctly will ensure results are logged in under the same unit consistently for trending purposes.

175

Importance of Sample Registration

- Having all the unit info registered to ensure correct results includes the following:
  - Unit/component type
  - Manufacturer/model
  - Correct oil type
  - Was sample taken when the oil changed (Y/N)?
- Correct data for registration is critical because different equipment will have different criteria:
  - For example the same particle count flagging limit would not apply to a hydraulic and a final drive, etc.
- How can you address incorrect sample registration?
  - Sample tags (QR Tags for equipment):
  - Your company's sampling and registration policy and procedures.
  - Ensure all units are created in myLab.

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Sample Registration: Key Points

- Samples can be registered via:
  - Mobile myLab app
  - myLab web portal
  - Manual Registration (Sample Cards)
- Samples can be registered individually or in batches through myLab by:
  - Components
  - Due samples
  - Routes
  - PM Definition

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Mobile App Sample Registration

- Fluid Life oil samples can be registered using :
  - Phone
  - Tablet
  - Other mobile device.
- The app can be downloaded at:
  - App Store (Apple/iOS devices)
  - Google Play (Android devices)
- If samples are registered in remote areas or while in airplane mode, the information will be transmitted back once in cellular range or connected to Wi-Fi.
- When the samples are received in the lab, they are scanned to pull up correct information.

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Mobile App Sample Registration

We will do a demonstration for this step:

- Equipment Tag Scan

- Manual Input

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Mobile App - Equipment Tag Scan

Step 1: Login

Step 2: Scan equipment tag

Step 3: Select components

Step 4: Scan sample bottle

Step 5: Verify Information

Step 6: Check for recently submitted samples.

181

Mobile App - Manual Input

Step 1: Login

Step 2: Enter unit information

Step 3: Select components

Step 4: Scan sample bottle

Step 5: Verify information

Step 6: Check for recently submitted samples.

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Agenda

- Fundamentals of Lubricants
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  - **Web Based**
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Web Based Sample Registration

- Samples can be registered individually or in batches through myLab.

- Workflows can be done as:
  - Register and print first, then collect sample:
    - Can include meter hours, date, if oil change was done.
  - Collect Sample, then register and optionally print:
    - A lid sticker is good for keeping track of samples taken.
  - Register in advance:
    - Blank label workflow.
      - Labels without a date and meter reading , go back and update information.
  - Route based (fixed equipment):
    - Routes need to be set up initially (Fluid Life can help with this).
    - Print out labels and apply to bottles as you sample at component.
  - PM Definition (mobile equipment):
    - Defined once which components are taken at a specific internal.
    - Not specific an individual unit, but can be applied to any unit (i.e heavy truck).

184

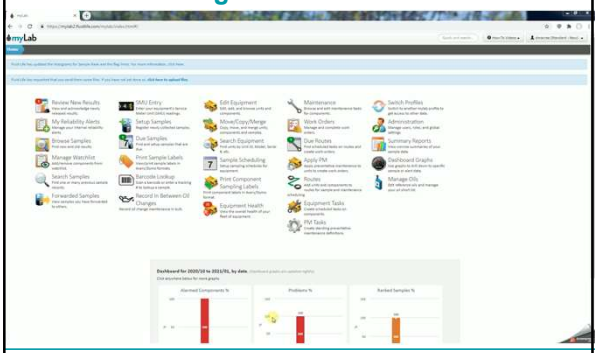
Web Based Sample Registration

- **We will do a demonstration for this step in the myLab Portal**

myLab

185

Web Based Registration



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Agenda

- Fundamentals of Lubricants
- Contamination Sources and Control Strategies
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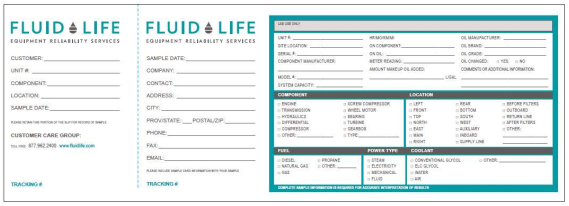
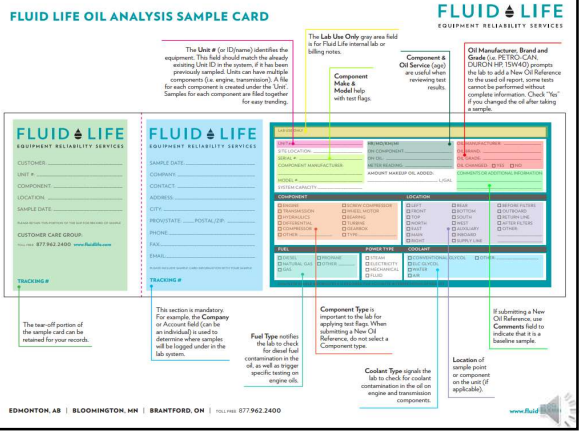
Sample Card Sample Registration



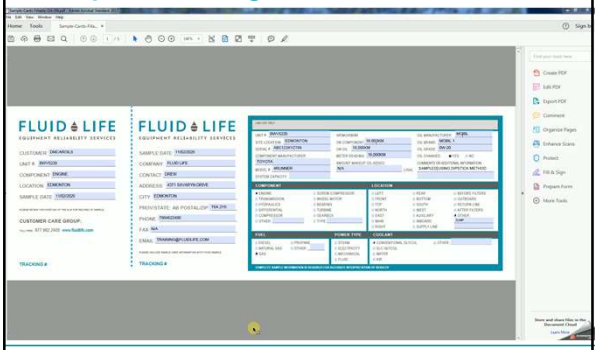
188

FLUID LIFE OIL ANALYSIS SAMPLE CARD



189

Sample Card Registration



190

Sample Card Sample Registration

- Common mistakes with sample cards:
  - Only the slip on left is filled out and the remainder of the card is left blank.
  - Oil type often left out or not filled out to match what is in use.
  - Card will be filled out with equipment ID in different forms lacking consistency.
  - The Grey box which reads “Lab Use Only” on the top right hand of the sample card:
    - Often misinterpreted to indicate the entire right half of the card isn’t supposed to be filled out.
    - If using cards, ensure the entire right hand portion is completed with as much information as possible.
  - Completed information slip on left is not torn off - this portion can be kept by you as a sample record.
  - Including serial numbers on cards helps find equipment if other data is missing.

191

Agenda

- Fundamentals of Lubricants
- Contamination Sources and Control Strategies
- Oil Sampling Basics
- Sample Registration
- **Data Interpretation**
  - **Overview of Data Interpretation**
  - Categories of testing
  - Establishing Limits

192

How to Interpret an Oil Analysis Report

- Problem Report (Yes or No)?
- How severe is the problem?
- Does the data match the new oil?
- What are the causes and effects?
- Results/Recommendations.

193

Data Interpretation Secrets to Success

- Look at all the data.
- Understand and explain each result.
- Do not jump to conclusions.
- Analyze for trends.

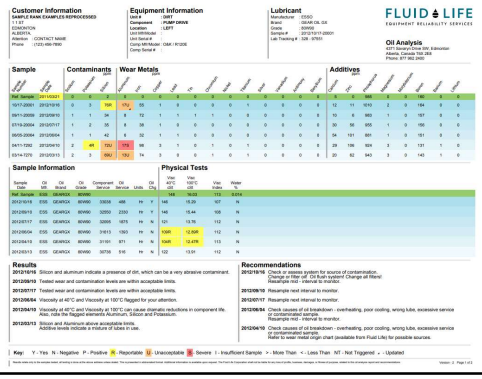
194

How to Make it Better

- For every sample, each result is assigned a Test Rank from two primary factors:
  - Percentile of latest result compared to histogram of similar samples:
    - Polling a database of >5,000,000 samples.
    - Based on ASTM D7720.
  - How far off trend the current result is to previous results for the same sample point:
    - Polling last 9 samples, same as the reported data.
    - Based on ASTM D7669.

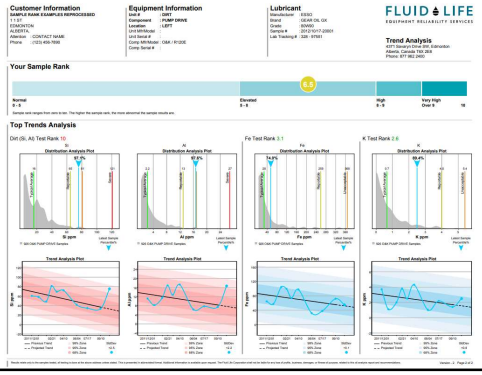
195

Sample Rank - Overview



196

Sample Rank - Overview



197

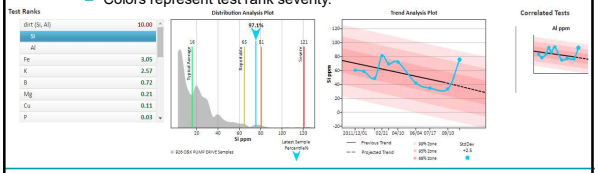
Sample Rank - Overview

- Sample Rank:
  - Based on 6 worst parameters using a weighted algorithmic equation.
  - As the rank increases, it moves up the rank bar and changes color.

198

Contextual Information

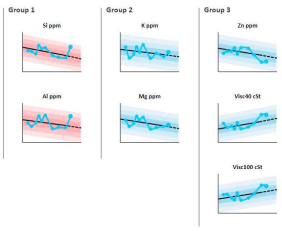
- Test Ranks:
  - Each test will have a rank based upon the distribution plot and trend analysis.
  - The correlated tests represents how the test correlates to others (they have similar trends) if shown on the right it represents a strong correlation.
  - Colors represent test rank severity.



199

Contextual Information

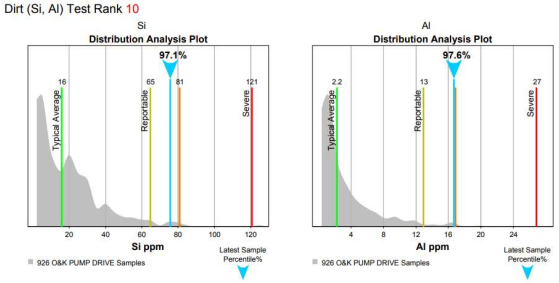
- Test Ranks:
  - You can view correlated tests and how the groups are how each test correlates to others within that group.



200

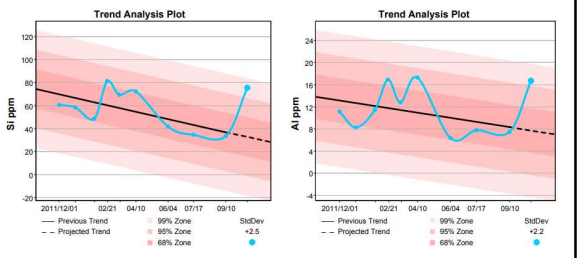
Contextual Information

Dirt (Si, Al) Test Rank 10



201

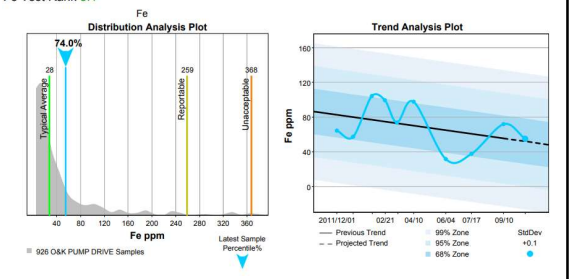
Contextual Information



202

Contextual Information

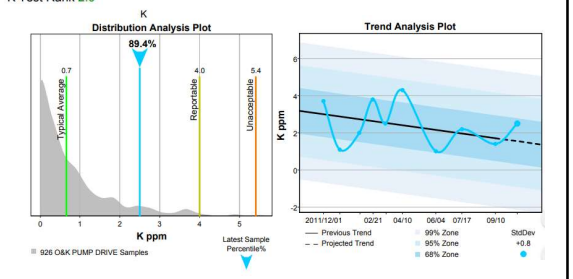
Fe Test Rank 3.1



203

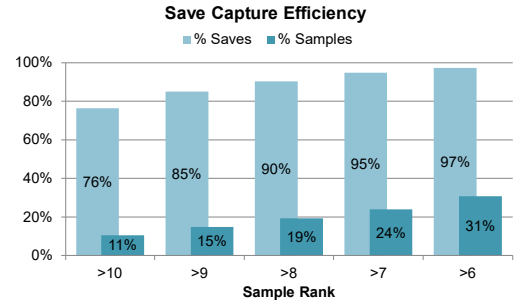
Contextual Information

K Test Rank 2.6



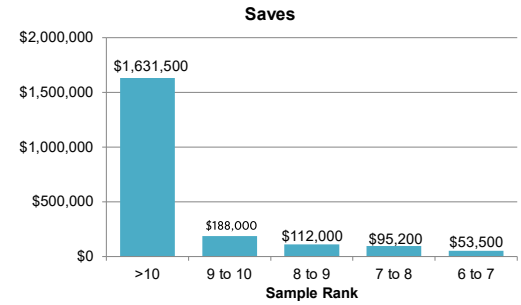
204

What is the value of Sample Rank?



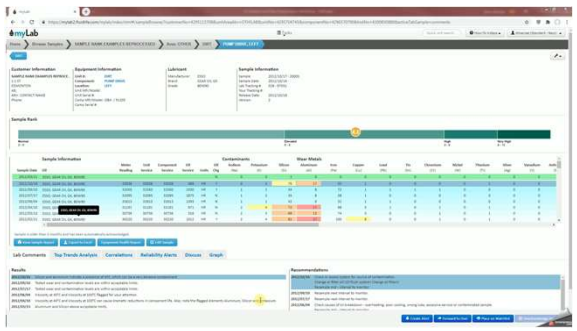
205

What is the value of Sample Rank?



206

myLab Quick Navigation



207

Agenda

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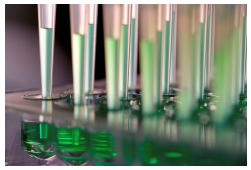
Categories of testing

FLUID PROPERTIES	CONTAMINATION	WEAR DEBRIS
	Spectrometry	
Viscosity	Water	Total Magnetic Iron
Acid/Base Number	Fuel Dilution	Filter Analysis
FTIR (Ox/NOx)	Glycol	Analytical Ferrography
Varnish Potential	Solids	X-Ray Fluorescence
RPVOT	Particle Count	OPC
RULER	OPC	

209

Oil Tests

- Each parameter's testing:
  - Application
  - Principle
  - Limitations
  - Interferences
  - Accuracy and Precision.
- Each parameter's data interpretation:
  - Most common cause of result:
    - Common mechanisms behind cause.
    - Correlating data.
  - Notable exceptions.



210

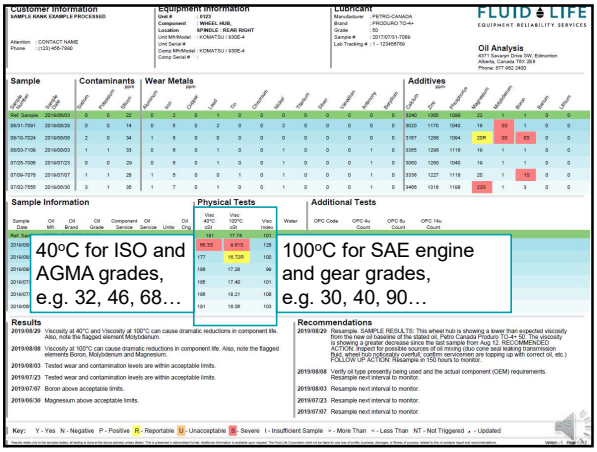
Physical Effects - Viscosity

- Application:
  - Routine on all samples, used to confirm grade and screen for contamination.
- Principle:
  - Sample is measured for how long it takes to flow under gravity through a capillary tube at a constant temperature.
- Limitations:
  - Highly contaminated samples may not yield a measurement at all.

211

Viscosity Example

212



213

214

40°C & 100°C - Common Cause

- Mixing With Another Product:
  - Will cause viscosity to change:
    - Thinner oil, water, fuel, refrigerant and/or solvent ingression will cause viscosity to decrease.
    - Thicker oil, water or glycol will cause viscosity to increase.
  - Mostly an issue with ISO VG oils, not as much in SAE oils.

215

40°C & 100°C Viscosity - Exceptions

- Oxidation:
  - Aging, thermal abuse or water contamination will lead to excessive oxidation resulting in an increase.
- Soot Contamination:
  - Will increase viscosity in engine oils, however greater attention should be given to the 100°C viscosity.
- Shearing:
  - Permanent shear will cause a decrease.

216

40°C & 100°C - Pitfalls

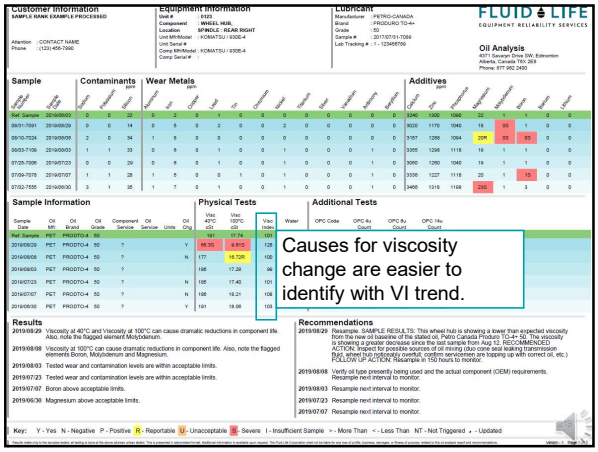
- 10% Rule For ISO VG Oils:
  - Allowable variance for each grade, smaller changes do not typically indicate problems.
- SAE J300 Table:
  - Allowable range for each grade, no exceptions.
- Masking Shearing Or Fuel Contamination:
  - Heavy oxidation or soot contamination can offset some of the decrease from shearing or fuel contamination.
- Look at Both 40°C And 100°C Values:
  - If 40°C is stable, but 100°C changes, then VI is changing indicating mixture of products.

217

Viscosity Index

- Application:
  - Routine on all samples, used to confirm correct product and check for shearing.
- Principle:
  - Calculated value based on both 40 and 100 °C viscosities using ASTM D2270 and standard number pulled based upon recorded viscosities.
- Limitations, Interferences, Accuracy, etc.:
  - Based on viscosity measurements.

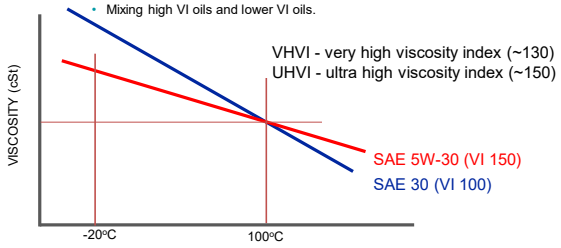
218



219

Viscosity Index - Common Cause

- Mixing With Another Product:
  - Will cause viscosity index to change:
    - Mixing single grades and multi-grades.
    - Mixing high VI oils and lower VI oils.



220

Viscosity Index - Exceptions

- Shearing:
  - VI additized oils, and some High Viscosity Index (HVI) oils will shear down:
    - Correlated by decrease in both 40°C and 100°C viscosities without top-up.

221

Viscosity Index - Pitfalls

- What am I Getting?
  - Not all labs measure both viscosities, some measure one then assume the VI and calculate the other.
- Ignoring Changes:
  - Decrease generally indicates shearing, but may represent mixing with lower VI product.
  - Increase always indicates top-off with a higher VI product.

222

Physical Effects - Crackle and KF (Water)

- Crackle Test:
  - Simple visual/auditory screening test can detect water as low as 150-200 ppm (depending on skill of the technician).
  - Hotplate at 120°C, senses detect bubbling or crackling of water.

- Karl Fischer (KF) Titration:
  - Sample is reacted with KF reagent (contains iodine) and current is passed between platinum plates. Sample reacts until water is gone.

223

Water

- Application:
  - Crackle is routine on all samples, used as screen for Karl Fischer and to identify gross contamination.
  - Consider routine Karl Fisher for hydraulic, turbine and paper machine oils or high-speed applications.
- Principle:
  - Crackle uses audio and visual indicators when sample is placed on hot plate.
  - Karl Fischer (KF) titrates with iodine to quantify water content.

224

Water

- Limitations:
  - Crackle is indicative from 150-250 to >1000 ppm.
  - Karl Fischer measures 10 ppm - 100%.
- Interferences:
  - Crackle can appear high if other volatile compounds (fuel, refrigerants) are present.
  - KF can skew high from ambient conditions at time of sample or testing.

225

Water Contamination Example

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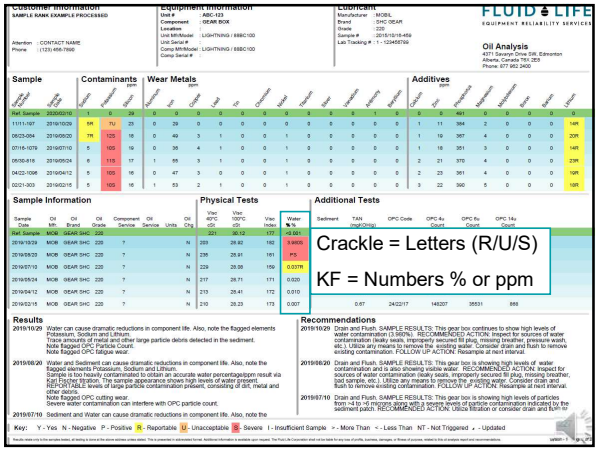
226



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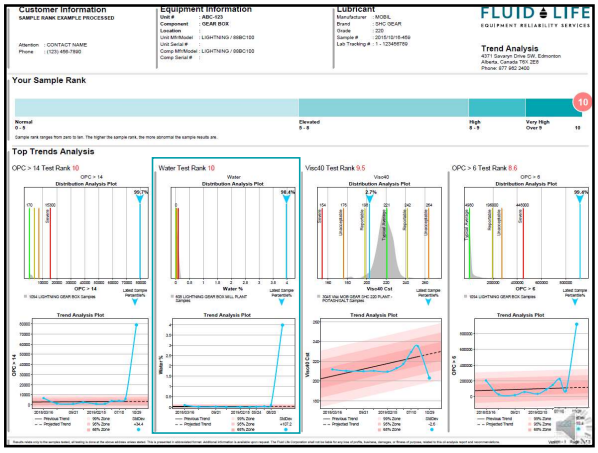


228

Water - Common Cause

- Moisture:
  - Ingression through air breather, filter or cover into the system, cooling system leak:
    - Evidenced by either a steady or sudden increase in water level.
  - Water is the #1 cause of diesel engine failures (oil related) and #2 cause of industrial equipment failures.

229

Water - Exceptions

- Inherently present:
  - All fluids contain some small amount of water, but varies based on manufacturing, storage, operating conditions, etc:
    - Evidenced by steady levels.
- Improper sampling:
  - Evidenced by anomalous water reading, not seen in next sample.

230

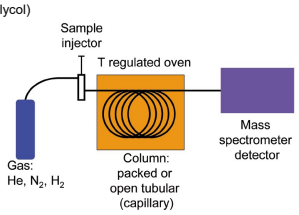
Water - Pitfalls

- Sample Location:
  - Samples taken from low points and stagnant lines typically show higher than representative results.
- Sampling Procedure:
  - Improperly flushed sample point will significantly alter result.
- Negative (N) Crackle:
  - Does not mean 'no' water.
  - Lower detection limit is about 150 - 250 ppm.

231

Chemical Effects - GC

- Gas Chromatography (GC):
  - Very good technique for quantifying the presence of contaminants like:
    - Fuel
    - Coolants (Glycol)



232

Fuel Contamination

- Limitations:
  - Heavily oxidized or high soot samples may not trigger this test.
  - If reference is at the top of the grade, it may not trigger.
- Interferences:
  - No significant interferences.
- Accuracy and Precision:
  - GC down to two decimal places, 0.01%.

233

Fuel Contamination

- Managing Fuel Contamination:
  - **Watch viscosity!**
  - Routine testing for fuel in critical applications.
  - If fuel is found, search for source, correct, change oil if below acceptable limit, or viscosity is out of grade.

234

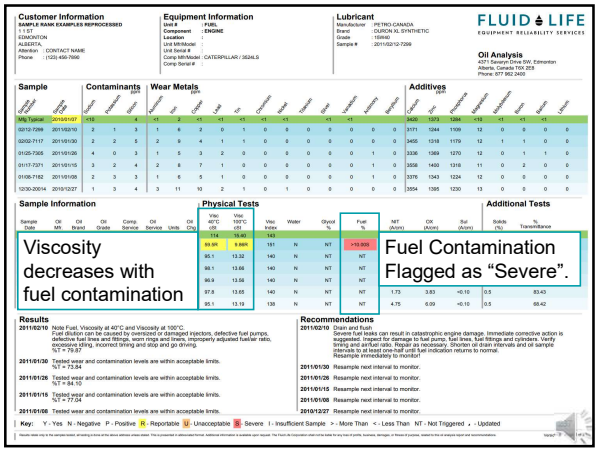
Fuel Contamination

- Detecting Fuel Contamination:
  - May see blue exhaust smoke due to fuel dilution (collapsed rings).
  - Sometimes you can detected by **odor**.
  - Fuel Sniffer - employs a Surface Acoustic Wave (SAW) Vapor Micro sensor to measure the concentration of fuel in used lubricating oil samples. It samples the "headspace" in a sample and detects absorbed hydrocarbons by a change in frequency of a surface acoustic wave.

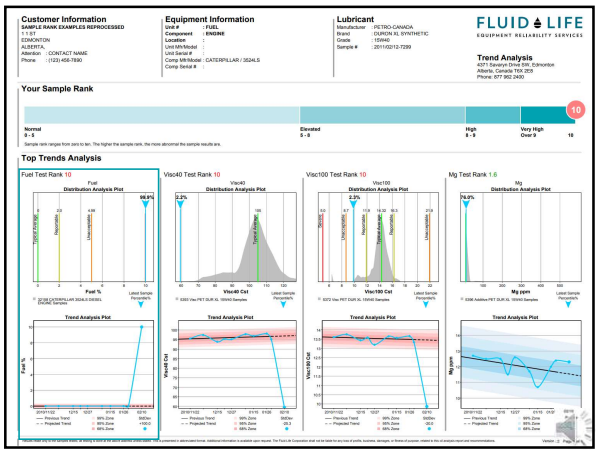
235

Fuel Contamination Example

236



237



238

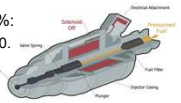
Fuel Contamination - Common Cause

- How can you get fuel in your oil?
  - Idling, lugging, damaged rings or liners.
  - Blow by, incorrect engine timing.
  - Fuel injector issues.
  - Damaged seals, damaged fuel pump (lobes, seals).
  - Oil drain extensions - excessive.
  - Excessive idling especially in cold weather conditions.
- Fuel is the # 2 cause of Diesel Engine Failures.

239

Fuel Contamination - Common Cause

- What will fuel do to your engine?
  - Reduce the viscosity of your oil.
  - Dilute critical additives.
  - Wash-down.
    - Remove or reduce the protective oil film on engine components (especially cylinder liners).
- Can cause engine fires if % fuel exceeds 5%:
  - 5% fuel can change an SAE 30 to an SAE 20.
- Recommended limits should be set for:
  - 1.5 = caution
  - 5.0 = critical



240

Fuel Contamination - Exceptions

- Sampling Timing:
  - If sample is collected after extensive idling, cold weather starting, frequent starting and/or short trip operation, then resampling properly will confirm if there is a true mechanical issue.

241

Chemical Effects - GC

- Application:
  - Triggered based on elevated Sodium and Potassium in all engine samples.
- Principle:
  - GC quantifies ethylene and propylene glycol by molecular sorting.
- Limitations:
  - No significant limitations.

242

Glycol Contamination

- Detecting glycol:
  - Gas Chromatography → triggered on 20 ppm **Na, K.**
  - Viscosity changes → glycol increases viscosity.
  - Blotter test → easy method for quick detection.
- Controlling Coolant:
  - Test a new oil sample to establish baseline limits for coolant (Sodium - Na, Potassium - K, Boron - B).
  - Set alarm limits to trigger a glycol test, usually 20 ppm of Na and/or K, to trigger Gas Chromatography (GC - glycol).
  - Monitor for glycol and potential sources of entry into machine.

243

Glycol Contamination Example

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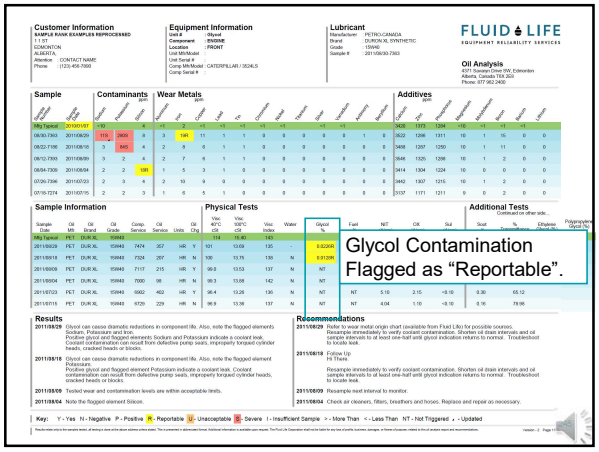
244



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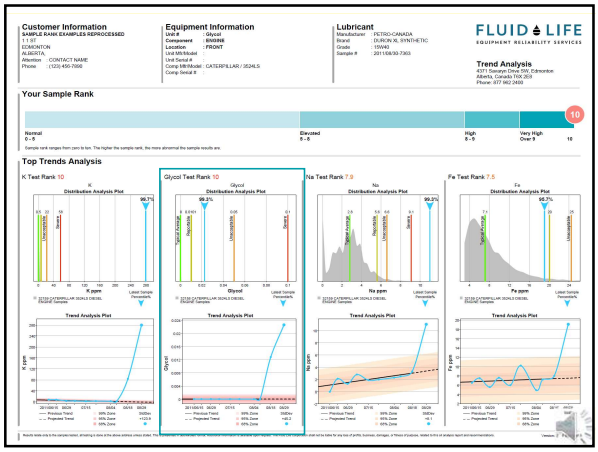


246

Glycol Contamination - Common Cause

- How does coolant get into a machine?
  - A point of ingress caused by:
    - Improperly torqued cylinder head, crack or hole in cylinder sleeve.
    - Seal damage or breakdown.
    - Mixing of oils leading to seal shrinkage.
    - Corrosion, damaged cooler core.
    - Cavitation (air bubbles along cylinder walls).
    - Electrochemical erosion (magnetic elements in fluid):
      - Cu, Sn, Pb with water will corrode Fe.
- What does it do to your machine?
  - Can cause:
    - Abrasive damage to liner and water pump seal rubbers.
    - Increased current corrosion of soft metals like aluminum and copper due to abrasion.
    - Liner pitting around top lower seal rubbers due to improper wash of coolant in area of sludge accumulation.
    - Filter failure due to formation of oil balls.
    - White smoke in diesel engine exhaust.

247

Glycol Contamination - Common Cause

- Oil ball - formation from glycol and motor oil:
  - Detergent (calcium sulfonate) + Glycol coolant → VERY hard precipitates.
  - Size range ~5 to 40 microns.
  - Abrasive wear from the hard particles, especially in soft bearing overlays.
  - Can plug filters.
- What does it do to your oil?
  - Can cause:
    - Increase in viscosity.
    - Formation of gels and emulsions (water presence).
    - Increase in Acid Number.
    - Impedance to oil flow in narrow tolerances.
    - Decreased lubrication efficacy.

248

Glycol Coolant Contamination - Exceptions

- Sampling Technique:
  - If sample is collected from a common sump or drain pan, or if sample tubing previously used to collect a coolant is re-used, then resampling properly will confirm if there is a true mechanical issue.

249

Glycol Coolant Contamination - Pitfalls

- Triggered Test:
  - Some newer formulations of coolants do not contain sodium or potassium additives.
- Coolant = Glycol + Additives:
  - No glycol does not mean there is no coolant leak, it simply means the glycol (base fluid) is not present and likely boiled off. Presence of both sodium and potassium mean additives are present and there is a definite coolant leak.

250

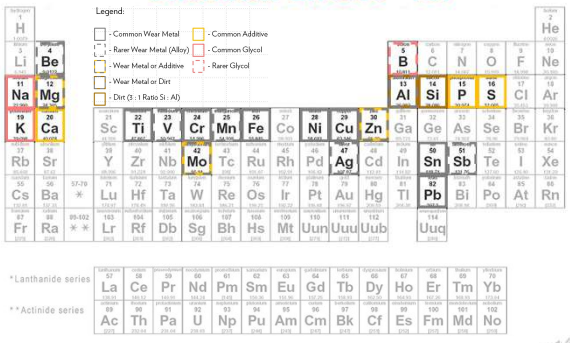
Chemical Effects - ICP

- Inductively Coupled Plasma (ICP):
  - Spectrometer measures the light of various wavelengths that is produced when a quantity of oil is "burned" at high temperature.
  - Elements are measured in ppm (parts per million).
  - Argon gas passed through a radio frequency induction coil to Temperatures >8000K.

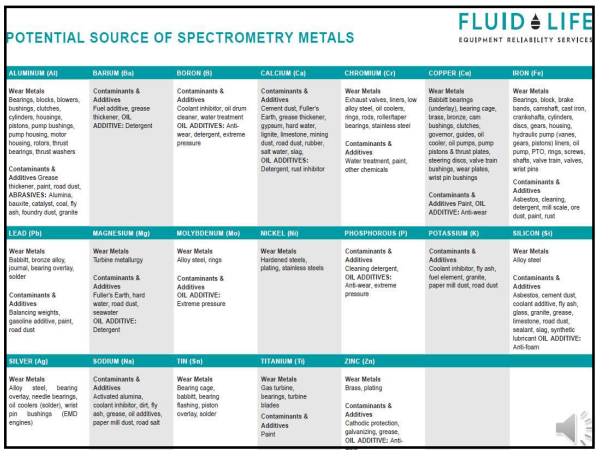


251

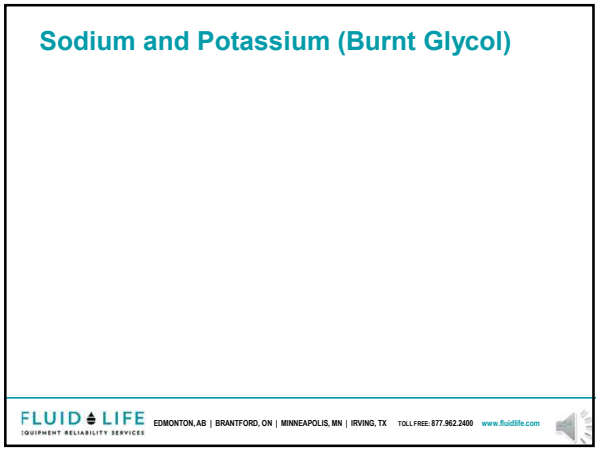
Chemical Effects - ICP



252


POTENTIAL SOURCE OF SPECTROMETRY METALS
FLUID LIFE
EQUIPMENT RELIABILITY SERVICES
ALUMINUM (Al)
Wear Metals
Bearings, blocks, blowers, bushings, clutches, cylinders, housings, pistons, pump bushings, pump housing, motor housing, rotors, thrust bearings, thrust washers
Contaminants & Additives Grease thickener, paint, road dust, ABRASIVES: Alumina, bauxite, catalyst, coal, fly ash, foundry dust, granite
BARRIUM (Ba)
Contaminants & Additives
Fuel additive, grease thickener, OIL ADDITIVE: Detergent
BORON (B)
Contaminants & Additives
Coolant inhibitor, oil drum cleaner, water treatment
OIL ADDITIVES: Anti-wear, detergent, extreme pressure
CALCIUM (Ca)
Contaminants & Additives
Cement dust, Fuller's Earth, grease thickener, gypsum, hard water, lignite, limestone, mining dust, road dust, rubber, salt water, slag,
OIL ADDITIVES: Detergent, rust inhibitor
CHROMIUM (Cr)
Wear Metals
Exhaust valves, liners, low alloy steel, oil coolers, rings, rods, rollerhaper bearings, stainless steel
Contaminants & Additives
Water treatment, paint, other chemicals
COPPER (Cu)
Wear Metals
Babbitt bearings (underlay), bearing cage, brass, bronze, cam bushings, clutches, governor, guides, oil cooler, oil pumps, pump pistons & thrust plates, steering discs, valve train bushings, wear plates, wrist pin bushings
Contaminants & Additives Paint, OIL ADDITIVE: Anti-wear
IRON (Fe)
Wear Metals
Bearings, block, brake bands, camshaft, cast iron, crankshafts, cylinders, discs, gears, housing, hydraulic pump (vanes, gears, pistons) liners, oil pump, PTO, rings, screws, shafts, valve train, valves, wrist pins
Contaminants & Additives
Asbestos, cleaning, detergent, mill scale, ore dust, paint, rust
LEAD (Pb)
Wear Metals
Babbitt, bronze alloy, journal, bearing overlay, solder
Contaminants & Additives
Balancing weights, gasoline additive, paint, road dust
MAGNESIUM (Mg)
Wear Metals
Turbine metallurgy
Contaminants & Additives
Fuller's Earth, hard water, road dust, seawater
OIL ADDITIVE: Detergent
MOLYBDENUM (Mo)
Wear Metals
Alloy steel, rings
Contaminants & Additives
OIL ADDITIVE: Extreme pressure
NICKEL (Ni)
Wear Metals
Hardened steels, plating, stainless steels
PHOSPHORUS (P)
Contaminants & Additives
Clearing detergent,
OIL ADDITIVES: Anti-wear, extreme pressure
POTASSIUM (K)
Contaminants & Additives
Coolant inhibitor, fly ash, fuel element, granite, paper mill dust, road dust
SILICON (Si)
Wear Metals
Alloy steel
Contaminants & Additives
Asbestos, cement dust, coolant additive, fly ash, glass, granite, grease, limestone, road dust, sealant, slag, synthetic lubricant OIL ADDITIVE: Anti-foam
SILVER (Ag)
Wear Metals
Alloy steel, bearing overlay, needle bearings, oil coolers (solder), wrist pin bushings (EMD engines)
SODIUM (Na)
Contaminants & Additives
Activated alumina, coolant inhibitor, dirt, fly ash, grease, oil additives, paper mill dust, road salt
TIN (Sn)
Wear Metals
Bearing cage, babbitt, bearing flashing, piston overlay, solder
TITANIUM (Ti)
Wear Metals
Gas turbine, bearings, turbine blades
Contaminants & Additives
Paint
ZINC (Zn)
Wear Metals
Brass, plating
Contaminants & Additives
Cathodic protection, galvanizing, grease,
OIL ADDITIVE: Anti-

253


Sodium and Potassium (Burnt Glycol)
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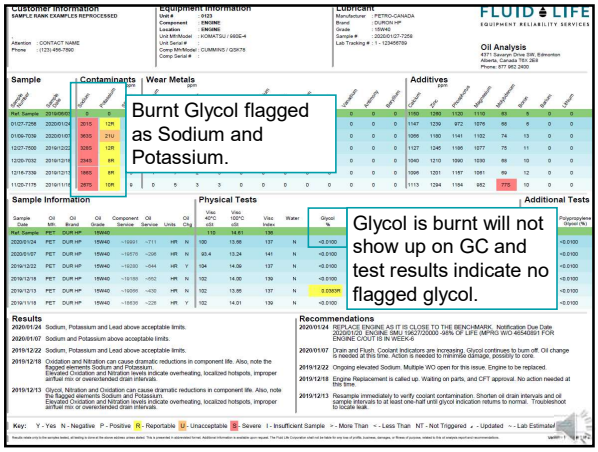
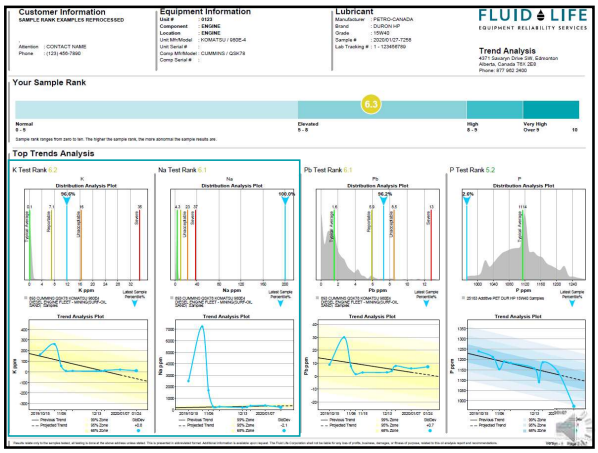
254


Customer Information
SAMPLE RANK EXAMPLES REPROCESSED
Equipment Information
Lubricant
FLUID LIFE
EQUIPMENT RELIABILITY SERVICES
Oil Analysis
Sample
Contaminants
Wear Metals
Additives
Burnt Glycol flagged as Sodium and Potassium.
Sample Information
Physical Tests
Additional Tests
Glycol is burnt will not show up on GC and test results indicate no flagged glycol.
Results
Recommendations
Key: Y - Yes N - Negative P - Positive R - Reportable U - Unacceptable S - Severe I - Insufficient Sample > - More Than < - Less Than NT - Not Triggered ↗ - Updated ~ - Lab Estimate

255



256

Sodium - Common Cause

- Coolant Leak:
  - Coolant enters through seal failure, cracked head or liner:
    - Evidenced by sudden appearance of sodium, may correlate against potassium and boron increases.
    - May not correlate against presence of glycol; sodium is an additive that will remain even if the glycol base fluid is boiled off. Oil change should reduce levels if issue has been addressed.
    - Evidence of bearing metals (lead, tin, copper) indicate a very serious problem.

257

Sodium - Exceptions

- Salt:
  - Sodium alone may appear if component is operated near salt water or if mobile and operated on salted road; not immediately damaging but may lead to shorter oil life from corrosion with prolonged exposure.
- Activated Alumina:
  - Sodium may appear in systems with acid scavenging systems using Activated Alumina or Selexsorb®; will lead to metal-salt formation causing valve stiction.

258

Sodium - Pitfalls

- New coolants:
  - Some newer coolants do not contain sodium based additives and will not trigger a glycol check by GC.
  - Consider adding glycol testing as routine testing for critical or expensive components.

259

Potassium - Common Cause

- Coolant Leak:
  - Coolant enters through seal failure, cracked head or liner:
    - Evidenced by sudden appearance of potassium, may correlate against sodium and boron increases.
    - May not correlate against presence of glycol; potassium is an additive that will remain even if the glycol base fluid is boiled off.
    - Evidence of bearing metals (lead, tin, copper) indicate a very serious problem.

260

Potassium - Exceptions

- Fly Ash:
  - Potassium appears as a combustion product of coal and wood. Evidenced by appearing only in components near a chimney stack; or sudden appearance after nearby forest fire .

261

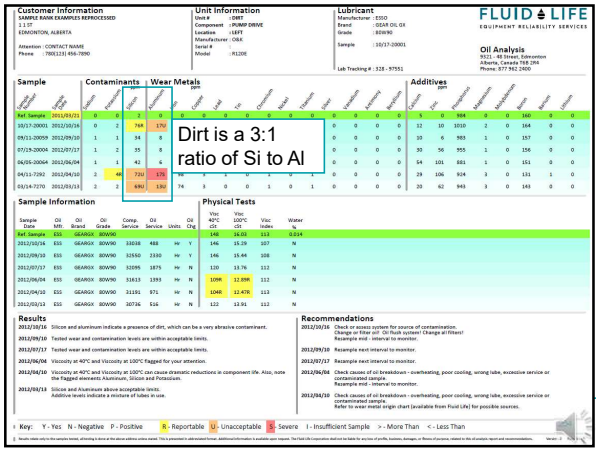
Potassium - Pitfalls

- New coolants:
  - Some newer coolants do not contain potassium based additives and will not trigger a glycol check by GC.
  - Consider adding glycol testing as routine testing for critical or expensive components.

262

Silicon and Aluminum example (dirt)

263



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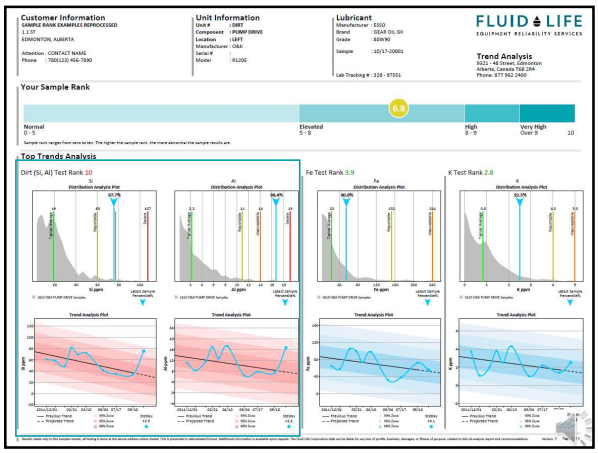


265

Silicon - Common Cause

- Dust and/or dirt:
  - Ingression through air breather, filter or cover into the system:
    - Evidenced by either a steady or sudden increase in silicon level, correlates with aluminum if dirt and wear metals if abrasive.
  - Possibly from improper sample taking:
    - Evidenced by anomalous silicon reading, not seen in next sample.

266

Silicon - Exceptions

- Sealant:
  - Overuse of silicone sealant/gasket maker entering the system:
    - Evidenced by sudden appearance after maintenance, especially with no increase in wear metals.
- Grease:
  - Leak between greased component and oil system:
    - Must use silicon-based grease on-site.

267

Silicon - Pitfalls

- Size matters:
  - Gross contamination may be too large for routine analysis to detect, even leading to wear particles outside detection range.
- Decreases not always good:
  - Sudden decreases without any action (filtration, fluid change) being taken may indicate contaminant has increased in size.
  - Follow through with large particle analysis to confirm.

268

Aluminum - Common Cause

- Wear Metal:
  - Aluminum is common in bearings, engine blocks, bushings and blades from blowers, rotors and turbochargers:
    - Evidenced by an increase in aluminum levels, usually in conjunction with iron.

269

Aluminum - Exceptions

- Dirt:
  - Dirt has elevated levels of aluminum:
    - Evidenced by silicon and aluminum in a ~3:1 ratio.
- Activated Alumina:
  - Aluminum will appear in systems with acid scavenging systems using Activated Alumina or Selexsorb®; will lead to metal-salt formation causing valve stiction.

270

Aluminum - Pitfalls

- Not all aluminum is wear:
  - Other than the usual pitfalls for a wear metal, high levels of aluminum may indicate a much less serious problem with a relatively simple and non-mechanical solution:
    - Aluminum originating from dirt may simply require an inspection and repair of the exclusion device (filter, breather) and its connection/seal.

271

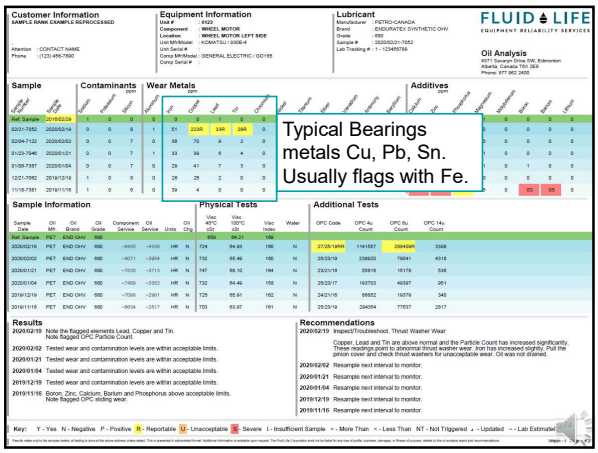
Iron

- Iron will commonly be with alloying elements or with bearing elements:
  - Copper, Lead, Tin (Bearing)
  - Chrome (alloying or plating)
  - Nickel (alloying or plating)
  - Chrome & Nickel (alloying or plating)

272

Iron with Copper, Tin, Lead (Bearing) example

273



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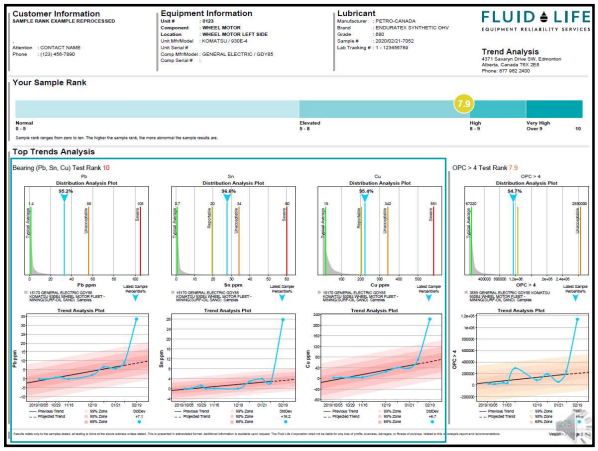

275

Iron - Common Cause

- Wear Metal:
  - Iron is the foundation element in all forms of steel, which is by far the most prevalent material in lubricated components:
    - Evidenced by increase in iron level, may directly relate to service or age of component.
    - Should see sacrificial metals first, e.g. soft metals like copper, tin and lead in bearing supported components or components with brass parts like gearboxes and pumps.
    - Alloys may be identified by presence of other metals like chromium, titanium, molybdenum and vanadium.

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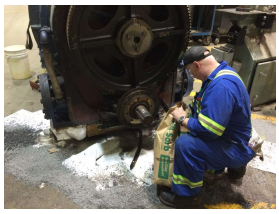
276

Iron - Exceptions

- Fuller's Earth:
  - Primary component of granular absorbent (kitty litter, floor dry) and some acid scavenging filters:
    - Evidenced by increases in iron, calcium and magnesium, and increase in particle count.



277

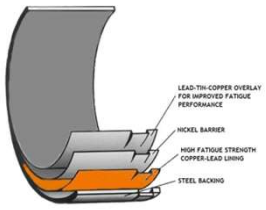
Iron - Pitfalls

- Not all iron is physical wear:
  - Some iron may come in the form of contamination from absorbent, or it could come from corrosion (rust) due to elevated water content and/or air entrainment.

278

Lead - Common Cause

- Wear Metal:
  - Lead is a common overlay in bearings (Babbitt), and a component of brass:
    - Evidenced by an increase in Lead levels, usually in conjunction with copper and/or tin.



279

Lead - Exceptions

- Solder:
  - Many solders contain lead, and are alloyed with tin:
    - Evidenced by increases in tin and an elevated Acid Number.
- Anti-Seize:
  - Some anti-seize compounds contain lead and usually molybdenum:
    - Evidenced by an increase in tin and molybdenum, and possibly particle counts immediately after maintenance.

280

Lead - Pitfalls

- Not All Lead Is Bad:
  - Other than the usual pitfalls for a wear metal, high levels of lead may indicate a much less serious problem with a relatively simple and non-mechanical solution:
    - Lead originating from solder or anti-seize may simply require an oil change to rectify the situation (remove acids eating the solder or the anti-seize contaminant).

281

Tin - Common Cause

- Wear Metal:
  - Tin is a common overlay in bearings (Babbitt) and as piston overlay (break-in coating), a component of brass, and found in parts like bearing cages and flashing, bushings and thrust plates:
    - Evidenced by an increase in tin levels, usually in conjunction with copper and/or lead.

282

Tin - Exceptions

- Solder:
  - Many solders contain tin:
    - Evidenced by increases in tin and lead or silver and an elevated Acid Number.
- Synthetic Oil Additive:
  - Some polyol ester fluids contain high levels of tin as remnants of the manufacturing process, or as a sacrificial anti-oxidant:
    - Evidenced by high levels of tin after oil changes or top-ups.

283

Tin - Pitfalls

- Size Matters:
  - Rapid failures may be too large for routine analysis to detect directly.
- Decreases Not Always Good:
  - Sudden decreases without any action (filtration, fluid change) being taken may indicate contaminant has increased in size.
  - Follow through with large particle analysis to confirm.

284

Copper - Common Cause

- Wear Metal:
  - Copper is a common overlay in bearings underneath the Babbitt, a component of brass/bronze, and found in parts like bearing cages, thrust and wear plates, bushings and guides:
    - Evidenced by an increase in copper levels, usually in conjunction with lead and/or tin, and sometimes zinc.

285

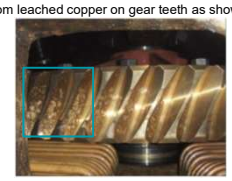
Copper - Exceptions

- Coolers:
  - Tubing in coolers and heat exchangers is often copper, new components will leach metals while they build up a protective oxidative layer:
    - Evidenced by elevated copper levels during first ~1500 hours of service which then vanish with subsequent oil changes.
- Anti-Seize:
  - Some anti-seize compounds contain copper:
    - Evidenced by an increase in copper, and possibly particle counts, immediately after maintenance.

286

Copper - Exceptions (cont'd)

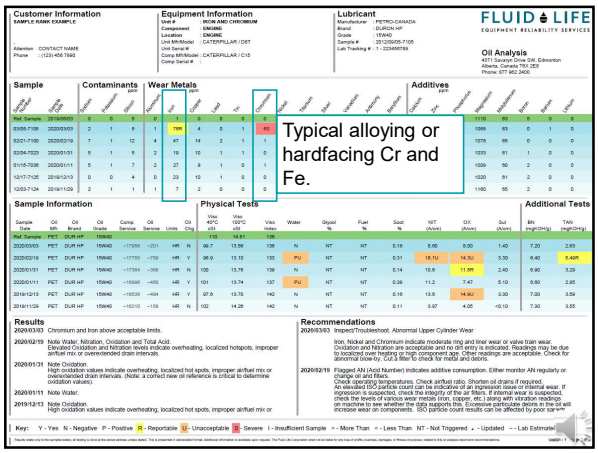
- Wrong Gear Oil:
  - Use of a sculpture-phosphorus EP additive in a copper or brass system will lead to chemical wear:
    - Evidenced by increase in copper in conjunction with either sudden appearance of phosphorus not previously detected (when R&O oil is normally used), or stable phosphorus and decrease in zinc (when AW oil is normally used).
    - Pitting from leached copper on gear teeth as shown below.



287

Iron and Chromium Example

288



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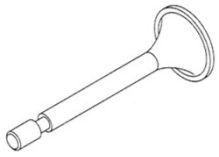
290

Chromium - Which Valve?

- Intake valve: often a chromium-nickel alloy.
- Exhaust valve: often a silicon-chromium alloy since it operates at higher temperatures (~1200°F / 649°C).



291

Chromium - Common Cause

- Wear Metal:
  - Chromium is a common coating for many steel parts like bearings, valves, rods and rings, and an alloy of both stainless steel and low alloy steel:
    - Evidenced by an increase in chromium, usually in conjunction with iron and generally follows higher silicon levels.

292

Chromium - Exceptions

- Rust Inhibitor:
  - Cooling water may contain chromium based rust inhibitors:
    - Evidenced by increases in either sodium or potassium, and possibly water content.

293

Chromium - Pitfalls

- Proportional?
  - Confirming if chromium is proportional or not with other metals like iron will differentiate if the wearing part is alloyed or coated, respectively.

294

Iron and Nickel Example

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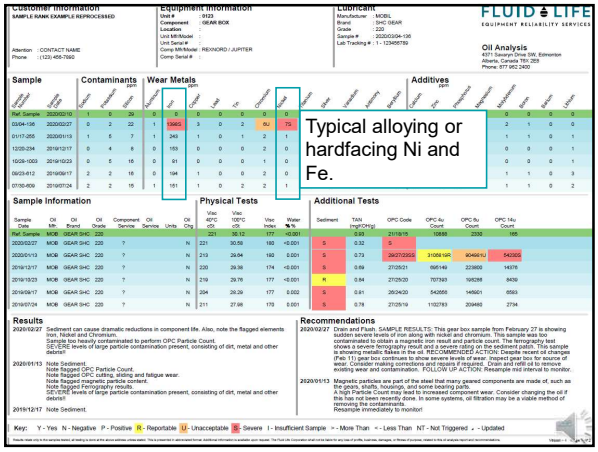
295



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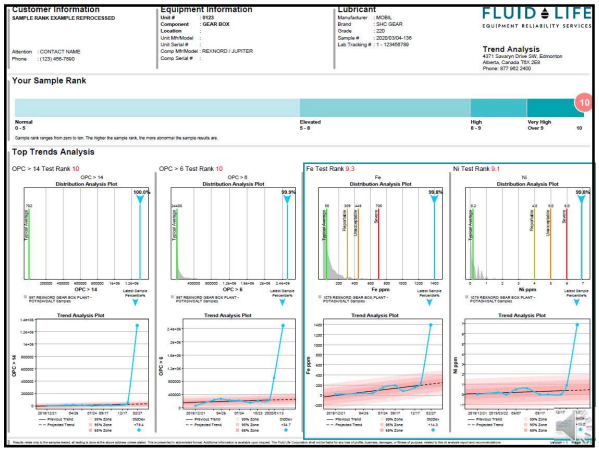

297

Nickel - Common Cause

- Wear Metal:
  - Nickel is a common alloy in many forms of steel or as plating on some parts:
    - Evidenced by an increase in nickel levels, usually in conjunction with iron.

298

Nickel - Exceptions

- Bearings:
  - Some bearings are being manufactured with nickel coating, leading to seemingly atypically high nickel levels during break-in periods:
    - Evidenced by high nickel on new components with a sudden decrease after an oil change and ~1500 hours of service.
- Anti-Seize
  - Some anti-seize compounds contain nickel:
    - Evidenced by an increase in nickel, and possibly particle counts, immediately after maintenance.

299

Nickel - Pitfalls

- Singular, Combined or Proportional?
  - Nickel on its own is often indicative of nickel parts, while nickel in conjunction with chromium is suggestive of coatings.
  - Confirming if nickel is proportional or not with other metals like iron will differentiate if the wearing part is alloyed or coated, respectively.

300

Other Tested Metals

- There are other metals that are tested for with the IPC but are not as common:
  - Titanium
  - Silver
  - Vanadium
  - Antimony
  - Beryllium

301

Titanium - Common Cause

- Wear Metal:
  - Titanium is used as an alloy in some bearings and turbine shafts:
    - Evidenced by an increase in titanium levels, usually in conjunction with iron, aluminum and/or nickel.

302

Titanium - Exceptions

- Paint:
  - Machinist's layout fluid used for checking gear mesh.
  - Also used as a brightener of paint, or for reflective finishes. Large-scale, recent painting may have migrated into lube system.

303

Titanium - Pitfalls

- Not All Jet Engines Fly:
  - It should be remembered that some stationary turbines are really aviation turbines with minor modifications, therefore these components may have one or more titanium alloyed parts.

304

Silver - Common Cause

- Wear Metal:
  - Silver is used as an overlay in some bearings (EMD locomotives engines, some gas turbines and most aviation engines), as an alloy in some bearing rollers and races, valve guide and cylinder liners:
    - Evidenced by an increase in silver levels, usually in conjunction with iron.

305

Silver - Exceptions

- Solder:
  - Some solders contain silver:
    - Evidenced by increases in silver and tin and an elevated Acid Number.
- Unfriendly Zinc:
  - Zinc is corrosive to silver, so use of an incorrect lubricant may lead to high silver levels through chemical wear, not physical wear:
    - Evidenced by elevated silver after appearance of zinc.
    - These applications require a tricresyl phosphate anti-wear additive.

306

Silver - Pitfalls

- Not All Silver Is Physical Wear:
  - Other than the usual pitfalls for a wear metal, high levels of silver may indicate corrosion:
    - Silver originating from a reaction with zinc will require an immediate fluid change and close monitoring to ensure the metal surface has not been grossly affected leading to physical wear.

307

Vanadium - Common Cause

- Wear Metal:
  - Vanadium is used as an alloy in some hard steels:
    - Evidenced by an increase in vanadium levels, usually in conjunction with iron.
  - Vanadium may be alloyed in some coatings:
    - Evidenced by an increase in vanadium levels, usually in conjunction with chromium.

308

Vanadium - Exceptions

- Crude Oil/Bunker Fuel:
  - Crude oil contains vanadium and it is not removed when making bunker fuel:
    - Evidenced by appearance of vanadium and nickel in conjunction with increase in solids or Pentane Insolubles (looking for traces of fuel ash).

309

Vanadium - Pitfalls

- Rarity:
  - Vanadium alloyed parts are not common, therefore this value is not often looked at.
  - Confirming if vanadium is proportional or not with other metals like iron or chromium will differentiate if the wearing part is alloyed or coated, respectively.

310

Antimony - Common Cause

- Wear Metal:
  - Antimony is used as an alloy in some steels:
    - Evidenced by an increase in antimony levels, usually in conjunction with iron.

311

Antimony - Exceptions

- Additive:
  - Some greases may contain antimony based EP additives, particularly marine greases.
  - In some rare cases antimony has shown up as part of a fuel's or oil's additive package:
    - Evidenced by an increase in antimony without a marked increase in iron.

312

Antimony - Pitfalls

- Low levels:
  - Antimony is used in such small quantities as an alloy that unless the lab is reporting below 1 ppm resolution, changes go unnoticed.
- Rarity:
  - Antimony additive greases are not common, therefore this value is not often looked at.

313

Beryllium - Common Cause

- Wear Metal:
  - Beryllium is found in some forms of bronze:
    - Evidenced by an increase in beryllium levels, usually in conjunction with a more prominent increase in copper and/or lead.
  - No exceptions, no pitfalls.

314

Additives

- The common additives are listed as PPM on oil analysis reports.
- Concentration of each type of additive are not able to be differentiated.
- Increased additive concentration may be from incorrect oil mixtures, after market additive packages greases, cleaning products, wear from components.

315

Wrong Oil Example

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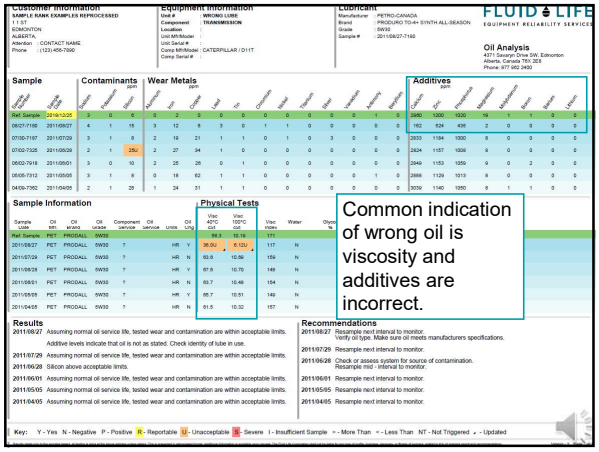


317

318

Calcium - Common Cause

- Oil Additive:
  - Detergent additives often use a calcium-based additive:
    - Evidenced by appearing in the new oil line, variations above 25% should be considered as mixing with another product or degradation.

319

Calcium - Exceptions

- Fuller's Earth:
  - Primary component of granular absorbent (kitty litter, floor dry) and some acid scavenging filters:
    - Evidenced by increases in iron, calcium and magnesium, and increase in particle count.
- Water and/or Salt:
  - Common contaminants like water, sea water and road dust contain calcium:
    - Evidenced by an increase in calcium and either an increase in water content or particle count.

320

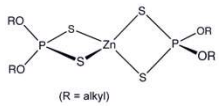
Calcium - Pitfalls

- Hidden Contaminants:
  - Detergent additive packages contain hundreds or thousands of ppm of calcium which masks small increases:
    - Evidence to be found in an increase in particle counts or water content.

321

Zinc - Common Cause

- Oil Additive:
  - Found in anti-wear additive packages:
    - Evidenced by appearing in the new oil line, variations above 25% should be considered as mixing with another product or degradation:
      - AW additive packages have relatively equal zinc and phosphorus concentrations (Zn attacks silver).
      - EP oils have phosphorus only.
      - R&O have neither.



(R = alkyl)

322

Zinc - Exceptions

- Wear Metal:
  - Zinc is also found in brass, some solders, galvanized metals and some forms of plating:
    - Brass wear evidenced more by increase in copper.
    - Solder attack evidenced more by tin or lead.
    - Galvanized metal evidenced more by iron.
    - Plating evidenced more by chromium or nickel.

323

Zinc - Pitfalls

- Hidden Wear Metals:
  - Many components with zinc as a wear metal use an AW oil which masks small increases:
    - Evidence to be found in an increase in associated metals.

324

Phosphorus - Common Cause

- Oil Additive:
  - Found in both Anti-Wear and Extreme Pressure additive packages:
    - Evidenced by appearing in the new oil line, variations above 25% should be considered as mixing with another product or degradation:
      - AW additive packages have relatively equal zinc and phosphorus concentrations (Zn attacks silver).
      - EP oils have phosphorus only.
      - R&O have neither.

325

Phosphorus - Exceptions

- Grease Additive:
  - Greases are also additive with EP and AW packages:
    - Evidenced by appearing in the new oil line, variations above 25% should be considered as mixing with another product.

326

Phosphorus - Pitfalls

- Clean Contamination:
  - Phosphorus is also found in some types of washing detergents:
    - Evidenced by appearance or increase after nearby washing has occurred.

327

Magnesium - Common Cause

- Oil Additive:
  - Detergent additives often use a magnesium-based additive:
    - Evidenced by appearing in the new oil line, variations above 25% should be considered as mixing with another product or degradation.

328

Magnesium - Exceptions

- Fuller's Earth:
  - Primary component of granular absorbent (kitty litter, floor dry) and some acid scavenging filters:
    - Evidenced by increases in iron, calcium and magnesium, and increase in particle count.
- Water and/or Salt:
  - Common contaminants like water, sea water and road dust contain magnesium:
    - Evidenced by an increase in magnesium and either an increase in water content or particle count.

329

Magnesium - Pitfalls

- Hidden Contaminants:
  - Detergent additive packages contain hundreds or thousands of ppm of magnesium which masks small increases:
    - Evidenced by an increase in particle counts or water content.

330

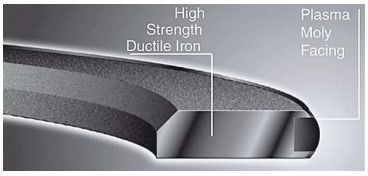
Molybdenum - Common Cause

- Friction Modifier:
  - Friction modifier or anti-slip additives often use a molybdenum-based additive:
    - Evidenced by appearing in the new oil line, variations above 25% should be considered as mixing with another product or degradation.

331

Molybdenum - Exceptions

- Wear Metal:
  - Piston rings and some alloys of steel contain molybdenum:
    - Evidenced by an increase in molybdenum and iron together.



332

Molybdenum - Pitfalls

- Energy Conservation:
  - Friction modifiers are used in energy conserving oils, which are needed in limited-slip differentials but cause problems in wet-clutch application:
    - Evidenced by appearance of molybdenum in non-additive oils, with no correlating Iron to suggest ring wear.

333

Boron - Common Cause

- Oil Additive:
  - Detergent additives often use a boron-based additive, but even some anti-wear or EP additives have smaller amounts:
    - Evidenced by appearing in the new oil line, variations above 25% should be considered as mixing with another product or degradation.

334

Boron - Exceptions

- Coolant Leak:
  - Some coolants may have a borate-based inhibitor:
    - Evidenced by sudden appearance of boron, may correlate against sodium and potassium increases.
    - May not correlate against presence of glycol; boron is an additive that will remain even if the glycol base fluid is boiled off.
    - Evidence of bearing metals (lead, tin, copper) indicate a very serious problem.

335

Boron - Pitfalls

- Clean Contamination:
  - Boron is also found in some types of washing detergents used for “steam-cleaning” drums and totes:
    - Evidenced by appearance or increase only after transferring from containers that have been cleaned.

336

Barium - Common Cause

- Oil Additive:
  - Detergent additives rarely use a barium-based additive:
    - Evidenced by appearing in the new oil line, variations above 25% should be considered as mixing with another product or degradation.

337

Barium - Exceptions

- Grease Additive:
  - Greases may also be additized with barium-based detergents:
    - Evidenced by appearing in the new oil line, variations above 25% should be considered as mixing with another product.

338

Barium - Pitfalls

- Never There/Never Check:
  - Barium is used as an additive so rarely it is not given a second glance:
    - If not usually there, then any trace of barium indicates contamination with another product.

339

Lithium - Common Cause

- Grease Contamination:
  - The most common thickener in grease is lithium:
    - Evidenced by the presence of lithium.
  - No exceptions, no pitfalls.

340

Additional Tests Done by Fluid Life

- FTIR - Soot, Nitration, Oxidation, Sulfation
- Potentiometric Titration - Acid Number and Base Number
- ISO - Particle Count
- Optical Particle Classification
- MPC (Membrane Patch Colorimetric (Varnish Potential)
- RPVOT - Rotation Pressure vessel oxidization test
- RULER - Remaining Useful Life Evaluation Routine
- X-Ray Fluorescence
- Filter test
- Total Magnetic Iron
- Analytical Ferrography

341

Fourier Transform Infra-Red (FTIR)

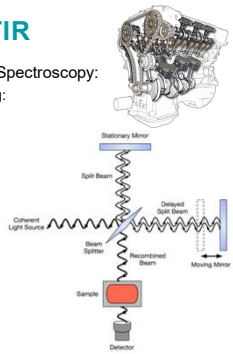
- Application:
  - Soot routine on all diesel engine samples, NOx and Ox on all natural gas engine samples, used to determine combustion problems.
- Principle:
  - Infra-red beam is passed through a static film of oil, resulting spectrum is subtracted from new oil spectrum to determine values.
- Limitations:
  - Oil specific calibration required for accurate measurements of water, fuel, glycol, ZDDP.
    - Fluid Life makes use of alternate and superior methods for these parameters.

342

Chemical Effects - FTIR

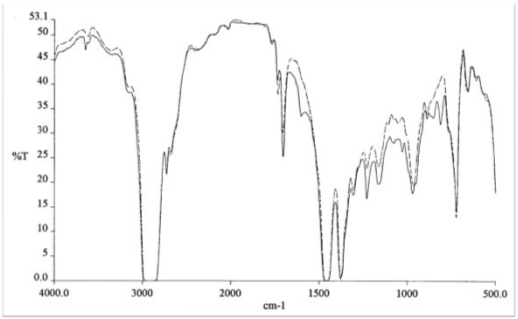
- Fourier Transform Infrared (FTIR) Spectroscopy:
  - Very good technique for measuring:
    - Soot
    - Nitration
    - Oxidation
    - Sulphation
    - Acid Number
    - Base Number

No ASTM method yet



343

FTIR

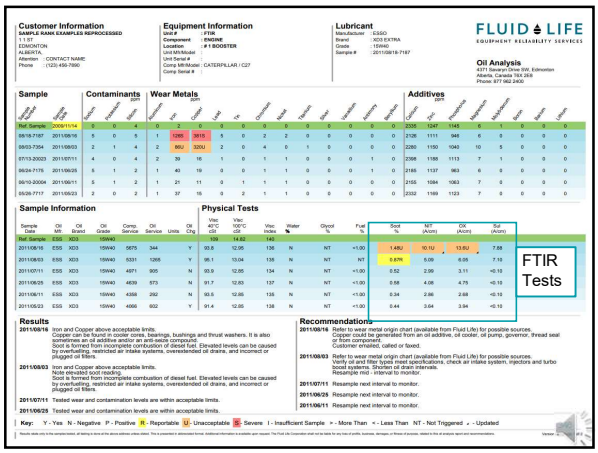


344

FTIR - Interferences

	LOWER DETECTION LIMIT	SENSITIVITY TO REFERENCE OIL	INTERFERENCES
GLYCOL	0.1%	Very High	Oxidation, water, antioxidants (phenols)
WATER	0.1%	Medium	High soot, additives, glycol, alcohols, acids
SOOT	0.01 Abs	Very Low	Particle size, engine type, particle density, water (high)
FUEL	2%	Ultra High	Aromatics, fuel type
OXIDATION	0.01 Abs	Low Ultra High (syn oils)	VI Improvers, dispersants, high water, esters, ketones
SULPHATION	0.01 Abs	Low	ZDDP, S-P EP, rust inhibitors
NITRATION	0.01 Abs	Low	VI improvers, dispersants
ANTIOXIDANT	1.0 Abs	Ultra High	Water, glycol, alcohols
ZDDP DEPLETION	0.01 Abs	Ultra High	Aromatics, fuel, silicon oxides

345



346

Soot Contamination

- Modern engines employ Exhaust Gas Recirculation (EGR) to reduce harmful emissions:
  - A percent of the exhaust gas is diverted back to the intake air through a cooler. This action allows:
    - More complete burning of NOx gases.
    - Introduces soot back into the intake gases.
    - Increases the overall soot load in motor oils.
    - Soot particles can become larger and more abrasive.
    - Uses up dispersant additive at a higher rate.

347

Soot Contamination

- Oil can hold some soot (dispersants, etc.). Acid from oxidation can make soot drop out of solution:
  - Soot causes:
    - Increased wear on components.
    - Deposits, and return oil-way blockage.
    - Loss of dispersancy.
    - Loss of an oil's antiwear and protective functions.
    - Increased filter plugging .
    - VISCOSITY INCREASE.

348

Soot Example

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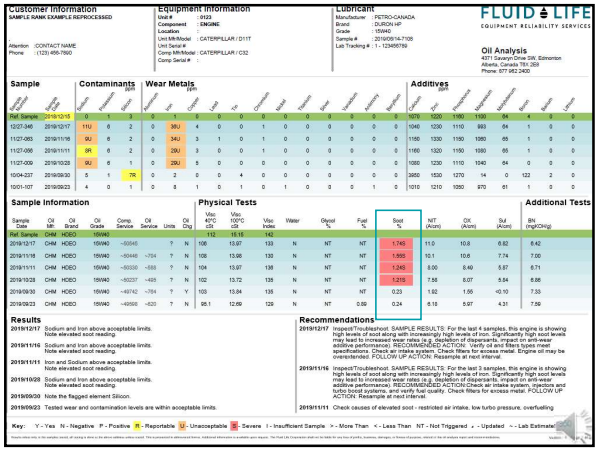
349



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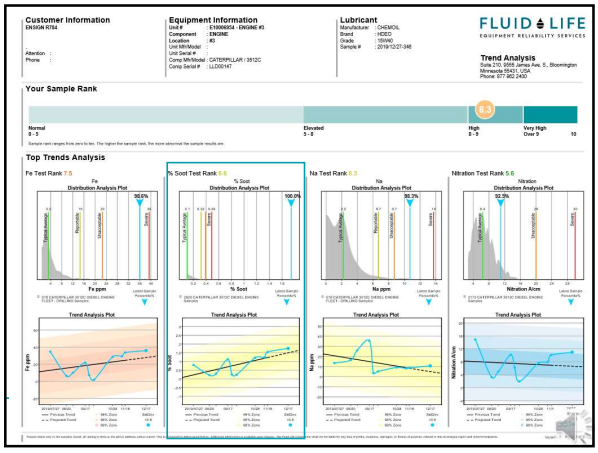


351

Soot Contamination - Common Cause

- Soot is particularly concerning in crankcase applications:
  - Can be caused by:
    - High blow by and wash down within the oil film on the cylinder and liner surfaces.
    - Incorrect timing (fuel rich, insufficient air in air : fuel ratio).
    - Low compression.
    - **Plugged air filters - poor airflow.**
    - Cold intake air temperatures.
    - Excessive idling and lugging.
    - Extended oil drain intervals.

352

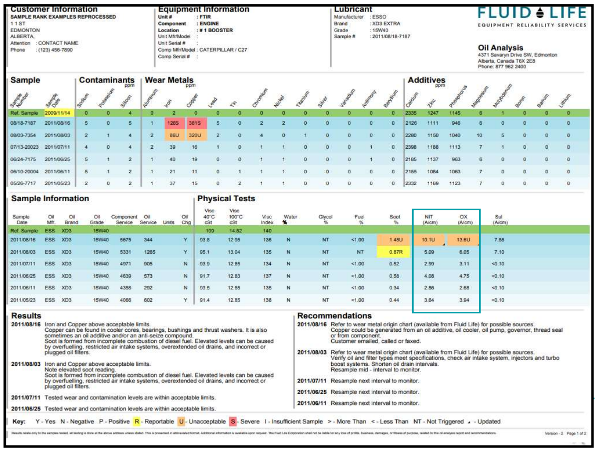
Soot Contamination

- Sampling Timing:
  - If sample is collected after extensive idling, then resampling properly will confirm if there is a true mechanical issue.
- Unit Of Reporting:
  - Soot can be reported as:
    - % Soot
    - % Allowable
    - % Transmittance

353

Nitration and Oxidation Example

354



Customer Information
SAMPLE RANK EXAMPLES REPROCESSED
1 1 ST
EDMONTON
ALBERTA,
Attention : CONTACT NAME
Phone : (123) 456-7890

Equipment Information
Unit # : FTIR
Component : ENGINE
Location : # 1 BOOSTER
Unit Mfr/Model :
Unit Serial # :
Comp Mfr/Model : CATERPILLAR / C27
Comp Serial # :

Lubricant
Manufacturer : ESSO
Brand : XD3 EXTRA
Grade : 15W40
Sample # : 2011/08/18-7187

FLUID LIFE
EQUIPMENT RELIABILITY SERVICES

Oil Analysis
4371 Savaryn Drive SW, Edmonton
Alberta, Canada T6X 2E8
Phone: 877 962 2400

Sample Number	Sample Date	Sodium	Potassium	Silicon	Aluminum	Iron	Copper	Lead	Tin	Chromium	Nickel	Titanium	Silver	Vanadium	Antimony	Beryllium	Calcium	Zinc	Phosphorus	Magnesium	Molybdenum	Boron	Barium	Lithium
Sample		Contaminants ppm			Wear Metals ppm												Additives ppm							
Ref. Sample	2009/11/14	0	0	4	0	2	0	0	0	0	0	0	0	0	0	0	2335	1247	1145	6	1	0	0	0
08/18-7187	2011/08/16	5	0	5	1	126S	381S	5	0	2	2	0	0	0	0	0	2126	1111	946	6	0	0	0	0
08/03-7354	2011/08/03	2	1	4	2	86U	320U	2	0	4	0	1	0	0	0	0	2280	1150	1040	10	5	0	0	0
07/13-20023	2011/07/11	4	0	4	2	39	16	1	0	1	1	0	0	0	1	0	2398	1188	1113	7	1	0	0	0
06/24-7175	2011/06/25	5	1	2	1	40	19	0	0	1	1	0	0	0	1	0	2185	1137	963	6	0	0	0	0
06/10-20004	2011/06/11	5	1	2	1	21	11	0	1	1	1	0	0	0	0	0	2155	1084	1063	7	0	0	0	0
05/26-7717	2011/05/23	2	0	2	1	37	15	0	2	1	1	0	0	0	0	0	2332	1169	1123	7	0	0	0	0

Sample Information / **Physical Tests**

Sample Date	Oil Mfr.	Oil Brand	Oil Grade	Component Service	Oil Service	Units	Oil Chg	Visc 40°C cSt	Visc 100°C cSt	Visc Index	Water %	Glycol %	Fuel %	Soot %	NIT (A/cm)	OX (A/cm)	Sul (A/cm)
Ref. Sample	ESS	XD3	15W40					109	14.82	140							
2011/08/16	ESS	XD3	15W40	5675	344		Y	93.8	12.95	136	N	NT	<1.00	1.48U	10.1U	13.6U	7.88
2011/08/03	ESS	XD3	15W40	5331	1265		Y	95.1	13.04	135	N	NT	NT	0.87R	5.09	6.05	7.10
2011/07/11	ESS	XD3	15W40	4971	905		N	93.9	12.85	134	N	NT	<1.00	0.52	2.99	3.11	<0.10
2011/06/25	ESS	XD3	15W40	4639	573		N	91.7	12.83	137	N	NT	<1.00	0.58	4.08	4.75	<0.10
2011/06/11	ESS	XD3	15W40	4358	292		N	93.5	12.85	135	N	NT	<1.00	0.34	2.86	2.68	<0.10
2011/05/23	ESS	XD3	15W40	4066	602		Y	91.4	12.85	138	N	NT	<1.00	0.44	3.64	3.94	<0.10

Results

2011/08/16 Iron and Copper above acceptable limits.
Copper can be found in cooler cores, bearings, bushings and thrust washers. It is also sometimes an oil additive and/or an anti-seize compound.
Soot is formed from incomplete combustion of diesel fuel. Elevated levels can be caused by overfuelling, restricted air intake systems, overextended oil drains, and incorrect or plugged oil filters.

2011/08/03 Iron and Copper above acceptable limits.
Note elevated soot reading.
Soot is formed from incomplete combustion of diesel fuel. Elevated levels can be caused by overfuelling, restricted air intake systems, overextended oil drains, and incorrect or plugged oil filters.

2011/07/11 Tested wear and contamination levels are within acceptable limits.

2011/06/25 Tested wear and contamination levels are within acceptable limits.

Recommendations

2011/08/16 Refer to wear metal origin chart (available from Fluid Life) for possible sources.
Copper could be generated from an oil additive, oil cooler, oil pump, governor, thread seal or from component.
Customer emailed, called or faxed.

2011/08/03 Refer to wear metal origin chart (available from Fluid Life) for possible sources.
Verify oil and filter types meet specifications, check air intake system, injectors and turbo boost systems. Shorten oil drain intervals.
Resample mid - interval to monitor.

2011/07/11 Resample next interval to monitor.

2011/06/25 Resample next interval to monitor.

2011/06/11 Resample next interval to monitor.

Key: Y - Yes N - Negative P - Positive R - Reportable U - Unacceptable S - Severe I - Insufficient Sample > - More Than < - Less Than NT - Not Triggered - Updated

Version - 2 Page 1 of 2

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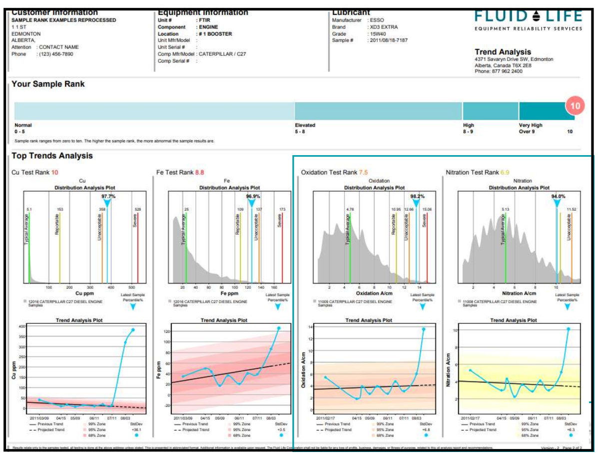

356

Nitration - Common Cause

- High Temperatures:
  - Reaction between nitrogen and oxygen at very high temperatures, typically seen in natural gas engines, creates NOx gases. Gases get into the oil on the cylinder walls and into the crankcase through blow-by:
    - Generally correlates with increase in viscosity and a increase in Acid Number (if measured).

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357

Nitration - Exceptions

- Advanced Timing:
  - Early combustion will increase nitration.
- Bio-Diesel Use:
  - Without proper adjustment to timing, bio-diesels can produce more nitration than conventional diesel at same setting.

358

Nitration - Pitfalls

- Mistaken Identity:
  - Visually nitration by-products are a reddish-brown, while oxidation by-products are dark brown to black.
  - Oil nitration causes light to dark brown deposits on cool parts of an engine such the piston skirts shown below.
  - Oil nitration has created a brown sludge as observed on the top end of the engine head on this Caterpillar engine.

359

Oxidation - Common Cause

- High Temperatures:
  - Inherent reaction between oil and oxygen is greatly accelerated by heat:
    - Generally correlates with increase in viscosity and Acid Number (if measured).
    - Remember that every 10ºC rise in sump operating temperature, over 80ºC, decreases the life of the oil by one half.

TEMPERATURE °C	HOURS	DAYS
80	10000	416
90	5000	208
100	2500	104
110	1250	52
120	625	26
130	313	13

360

Oxidation - Pitfalls

- Mistaken Identity:
  - Oxidation by-products may take on a crystalline form which is often mistaken as soot, to the untrained eye. Always confirm with analysis.
  - Below is a view of the inside of the engine block observed from the lower portion of the block. The interior of the block was coated with a dark brown to black deposit as a result of oil oxidation.
  - Photo below of a normal and plugged oil suction screen.

361

Sulfation - Common Cause

- sulfur In Fuel:
  - Sour fuel allows sulfur to be burned in combustion chamber, creating oxides of sulfur which poison catalytic converter systems:
    - Generally correlates with an increase in viscosity and Acid Number (if measured).

362

Sulfation - Exceptions

- sulfur In Oil:
  - The sulfur content in some oils, either from the base stock or from the additives, being burned in the combustion chamber may contribute to this value.

363

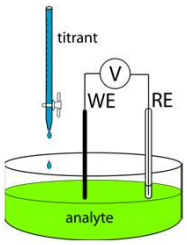
Sulfation - Pitfalls

- Not Requested:
  - Since most fuels and oils contain very little sulfur, this test must be requested by users of sour fuels or Group I oils.

364

Chemical Effects - Potentiometric Titration

- Used to titrate a sample to determine (via electric conductivity):
  - Acid Number (oxidation).
  - Base Number (detergents).
  - Reported in mg KOH/g.



365

Acid Number - Potentiometric Titration

- Application:
  - Used to extend drain intervals, and as an indication of oxidation.
  - Can be used on any oil with expected results >0.1 mg KOH/g, preferred choice for darker samples.
- Principle:
  - Sample is titrated with a base to a potentiometric (mV) endpoint to quantify acid content.

366

Acid Number - Potentiometric Titration

- Limitations:
  - Not a strong indicator of problems in large reservoir applications on its own, consider adding RPVOT or similar in such cases.
- Interferences:
  - High water content samples may not be accurate.
- Accuracy And Precision:
  - Repeatability: < 11.7% 19 times out of 20.
  - Reproducibility: < 44% 19 times out of 20.

367

Base Number - Potentiometric Titration

- Application:
  - Used to determine oil change intervals in gasoline, natural gas and diesel engines.
- Principle:
  - Sample is titrated with an acid to quantify base content, a.k.a. Reserve Alkalinity.
  - Engine manufacturers recommend lubricants should have base numbers 20X higher than the sulfur level of the diesel fuel used.

368

Base Number - Potentiometric Titration

- Limitations:
  - Can only be performed on oils with a Base Number additive package.
- Interferences:
  - No significant interferences.
- Accuracy And Precision:
  - Repeatability: < 5% 19 times out of 20
  - Reproducibility: < 7% 19 times out of 20

– AN and BN tests are sometimes referred to as **neutralization** tests.

369

Acid Number and Base Example

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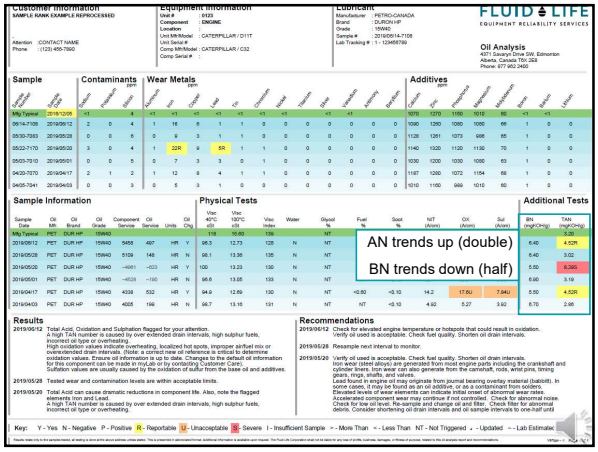
370



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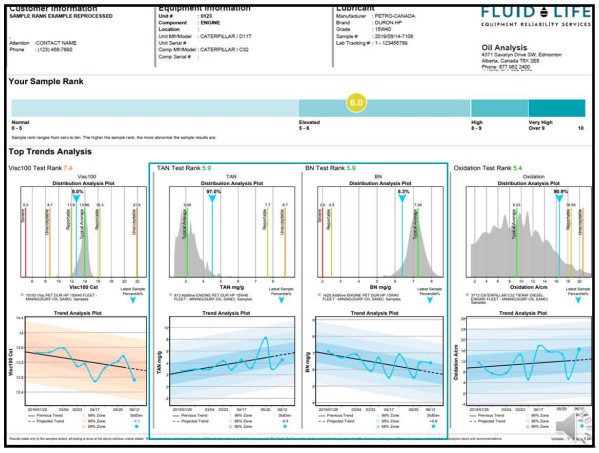


372

Acid Number - Common Cause

- Extended Service:
  - Normal operation results in a steady rise in Acid Number until oxidation inhibitor is depleted, then increase becomes exponential.
  - Can correlate with small increases in viscosity.
  - It is generally thought that a lubricant only begins to degrade after it has been put into service, but technically it begins to degrade immediately following blending.

373

Acid Number - Exceptions

- High Temperature:
  - Elevated operating temperatures will result in dramatic increase in acid production.
- Water Content:
  - Elevated levels of water will contribute to greater acid production.

374

Acid Number - Pitfalls

- Not Trending:
  - Often the trend of the acid is of greater importance than the actual value.
- Problems Diluted:
  - Large volume reservoirs dilute changes in acid number, which are more readily seen with an RPVOT test.

375

Base Number - Common Cause

- Extended Service:
  - Normal operation results in a steady decrease in Base Number until oxidation inhibitor is depleted, then decrease becomes exponential:
    - Can correlate with small increases in viscosity.

376

Base Number - Exceptions

- High Temperature:
  - Elevated operating temperatures will result in dramatic increase in acid production, thus lowering the Base Number.
- Water Content:
  - Elevate levels of water will contribute to greater acid production, thus lowering the Base Number.

377

Base Number - Pitfalls

- Not For Every Application:
  - Base Number measures additive performance rather than by-products of oxidation, therefore the oil must contain a Base Number additive. Typically only diesel engine oils, some gasoline and natural gas engine oils.

378

Particle Effects - ISO Particle Count

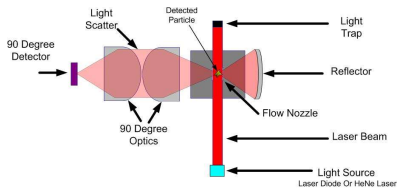
- Application:
  - Used to determine count of particulate >4 µm up to 100 µm in critical systems; hydraulics, compressors, turbines, paper machines, transmissions.
- Principle:
  - Laser is shone through a thin film of oil in motion, measurement of the blockage of light (shadows) equate to sizing and quantification of particulate.

379

ISO Particle Count

- Particles in a sample fluid flow through the object cell under controlled flow and volume conditions.

Top Down View of Particle Counter



380

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EQUIPMENT RELIABILITY SERVICES

UNDERSTANDING ISO PARTICLE COUNTS

Example

SIZE (MICRONS)	COUNT LARGER THAN SIZE
4	2136
6	463
10	161
14	63
20	29
50	6
75	2
100	1

ISO 4406:99 $R_4/R_6/R_{14}$

2136 particles > 4 microns/mL
463 particles > 6 microns/mL
63 particles > 14 microns/mL

MORE THAN	UP TO AND INCLUDING	RANGE NUMBER (R)
80000	160000	24
40000	80000	23
20000	40000	22
10000	20000	21
5000	10000	20
2500	5000	19
1300	2500	18
640	1300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8
0.64	1.3	7
0.32	0.64	6
0.16	0.32	6
0.08	0.16	4
0.04	0.08	3
0.02	0.04	2
0.01	0.02	1

A sample is given a fluid cleanliness rating using the table to the right. To do this, the number of particles greater than three size ranges (4, 6 and 14 microns) are determined in the equivalent of one millilitre of sample.

In the example shown, the particle count distribution shown translates to an ISO rating of 18/16/13 using the corresponding Range Number (R).

381

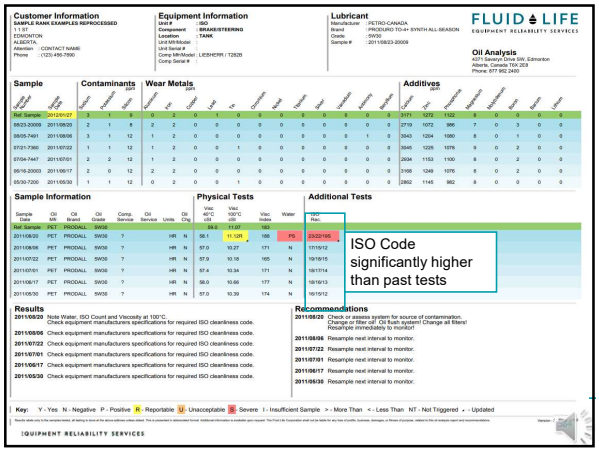
ISO Particle Count

- Limitations:
  - Particulate must be >4 µm and <100 µm to be counted.
  - Only counts particulate, does not identify.
- Interferences:
  - Improperly prepared sample will lead to water and air bubbles to be counted as particulate.
- Accuracy And Precision:
  - Repeatability: ± 50% of count, ± 1 ISO Code.
  - Reproducibility: ± 50% of count, ± 1 ISO Code.

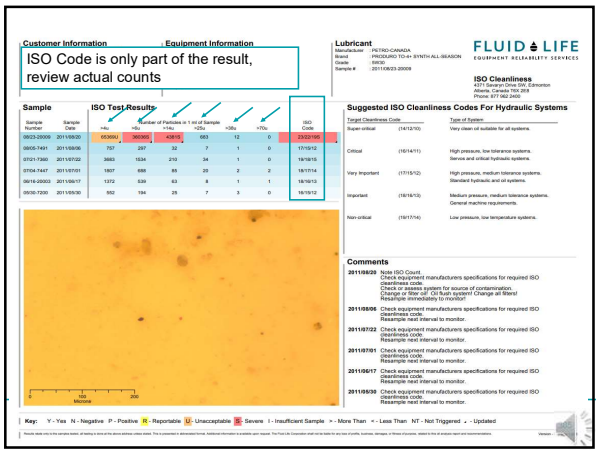
382

Particle Count example

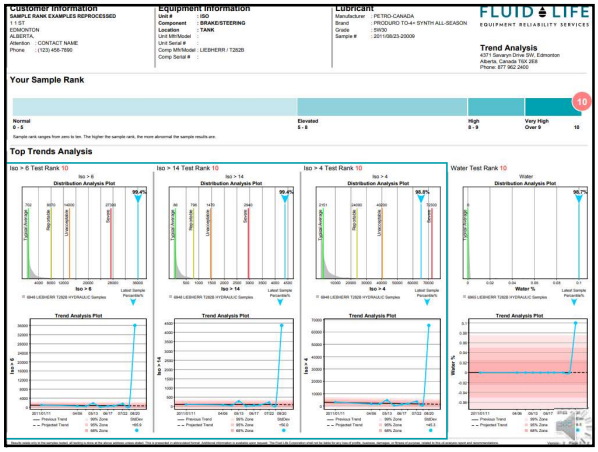
383



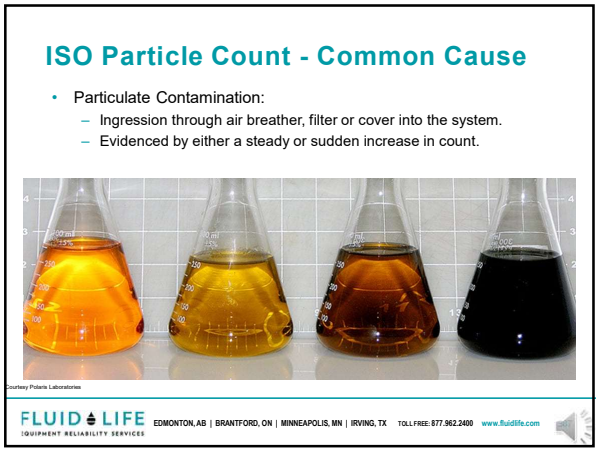
384


ISO Code is only part of the result, review actual counts
Customer Information
Equipment Information
Lubricant
FLUID LIFE
EQUIPMENT RELIABILITY SERVICES
Sample
ISO Test Results
Suggested ISO Cleanliness Codes For Hydraulic Systems
Comments
Key: Y - Yes N - Negative P - Positive R - Reportable U - Unacceptable S - Severe I - Insufficient Sample > - More Than < - Less Than NT - Not Triggered ✓ - Updated

385


Customer Information
Equipment Information
Lubricant
FLUID LIFE
EQUIPMENT RELIABILITY SERVICES
Trend Analysis
Your Sample Rank
Normal
Elevated
High
Very High
Top Trends Analysis
Iso > 6 Test Rank 10
Iso > 14 Test Rank 10
Iso > 4 Test Rank 10
Water Test Rank 10
Distribution Analysis Plot
Trend Analysis Plot

386


ISO Particle Count - Common Cause
Particulate Contamination:
Ingression through air breather, filter or cover into the system.
Evidenced by either a steady or sudden increase in count.
Courtesy Polaris Laboratories
FLUID LIFE
EQUIPMENT RELIABILITY SERVICES
EDMONTON, AB | BRANTFORD, ON | MINNEAPOLIS, MN | IRVING, TX
TOLL FREE: 877.962.2400
www.fluidlife.com

387

ISO Particle Count - Exceptions

- Improper Sampling:
  - Evidenced by anomalous particle count, not seen in next sample.
- Filter Failure:
  - Sudden increase in particle count, in conjunction with near zero differential pressure across the filter.
- Incorrectly Installed Filter:
  - Evidenced by a rise in particle count after filter replacement.

388

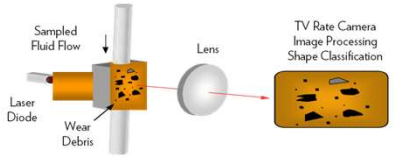
ISO Particle Count - Pitfalls

- Sample Location:
  - Samples taken from low points and stagnant lines typically show higher than representative results.
- Sampling Procedure:
  - Improperly flushed sample point will significantly alter result.
- Size Matters:
  - Will not correlate with spectrographic data, which measures <5 µm.

389

Particle Effects - OPC

- Optical Particle Classification:
  - Identifies particulate based on size, shape and type.
  - A laser illuminates fluid sample from behind the flow cell, a camera takes a picture for processing.
  - Measures particles in the range of ~ 4µm to < 100µm.



390

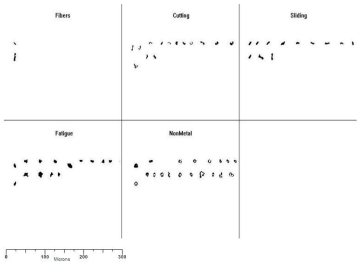
OPC - Classification Guidelines

- Optical Particle Characterization:
  - Orientation of particles can change characterization.
  - Cutting - long, curved or curly, C-shaped particles.
  - Sliding - long, straight particles with length greater than width.
  - Fatigue - "round" particles; length roughly equal to width, with jagged, irregular edges.
  - Non-Metals:
    - Water:
      - dark circles with bright centered.
    - Air:
      - dark round circles; all dark or small bright centers.
  - Fibers
    - long and partially transparent; possible filter issue.

391

OPC - Classification Table

- Computer will sort particles into each category - however, orientation of the particles will affect the results.

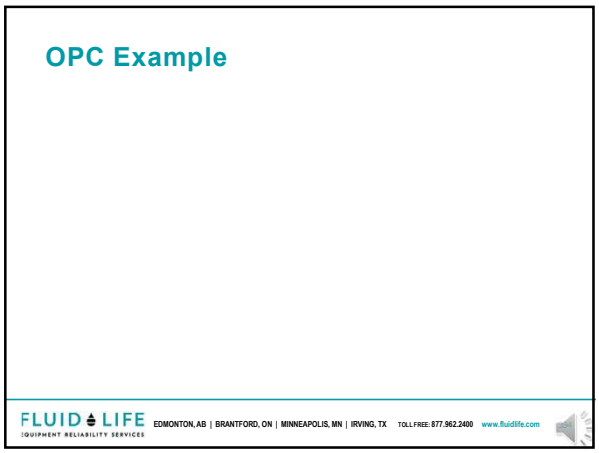


392

OPC

- Limitations:
  - Shape identification is only of particles >20 µm.
  - Limited measurement for particles >100 µm.
- Interferences:
  - No significant interferences.
- Accuracy And Precision:
  - Quantification same as ISO particle count.

393


OPC Example
FLUID LIFE
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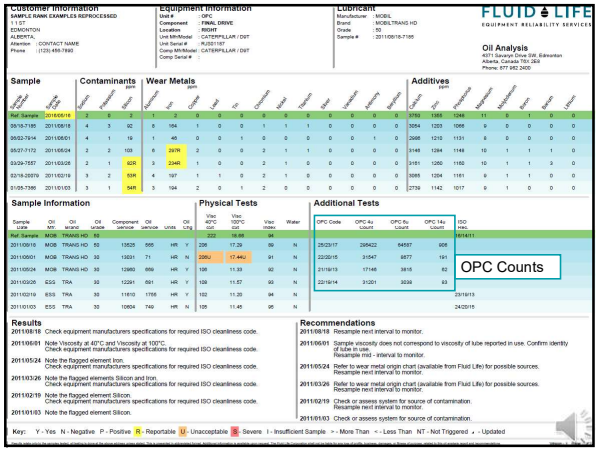
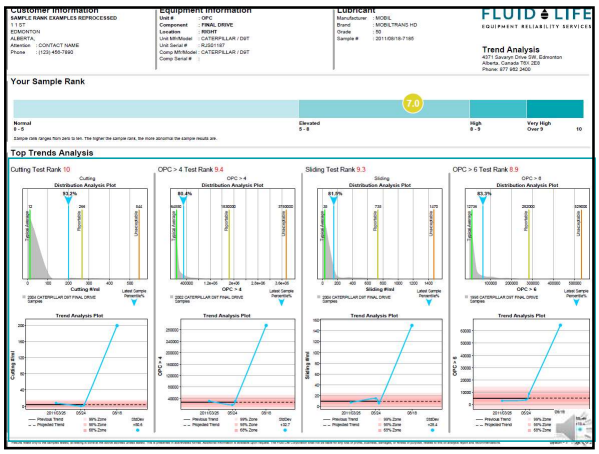
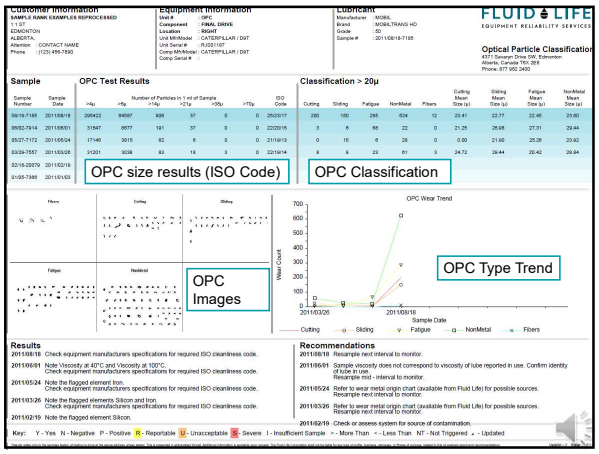
394


Customer Information
Equipment Information
Lubricant
FLUID LIFE
EQUIPMENT RELIABILITY SERVICES
Oil Analysis
Sample
Contaminants
Wear Metals
Additives
Sample Information
Physical Tests
Additional Tests
OPC Counts
Results
Recommendations
Key: Y - Yes N - Negative P - Positive R - Reportable U - Unacceptable S - Severe I - Insufficient Sample > - More Than < - Less Than NT - Not Triggered ↓ - Updated

395


Customer Information
Equipment Information
Lubricant
FLUID LIFE
EQUIPMENT RELIABILITY SERVICES
Trend Analysis
Your Sample Rank
7.0
Normal
Elevated
High
Very High
Top Trends Analysis
Cutting Test Rank 10
OPC > 4 Test Rank 9.4
Sliding Test Rank 9.3
OPC > 6 Test Rank 8.9
Distribution Analysis Plot
Trend Analysis Plot

396



397

OPC - Common Cause

- Particulate Contamination:
  - May indicate ingression through air breather, filter or cover into the system.
  - May indicate internal generation of wear/contaminants.
  - May indicate manufacturing debris is present.
  - May indicate improper sampling:
    - Evidenced by either a steady or sudden increase in particle count.

398

OPC - Exceptions

- Improper Sampling:
  - Evidenced by anomalous particle count, not seen in next sample.
- High Wear Rates:
  - Abnormal wear will cause increase in particle count and be evident in classification.

399

OPC - Pitfalls

- Sample Location:
  - Samples taken from low points and stagnant lines typically show higher than representative results.
- Sampling Procedure:
  - Improperly flushed sample point will significantly alter result.
- Size Matters:
  - Will not correlate with spectrographic data, which measures <5 µm.

400

Varnish Potential (MPC)

- Membrane Patch Colorimetry.
- Application:
  - Used in large volume and/or high speed systems; hydraulic, compressor, turbine, pump.
- Principle:
  - A filter/Membrane Patch is measured with a spectrophotometer for Color indicators of varnish precursors in the sample.

401

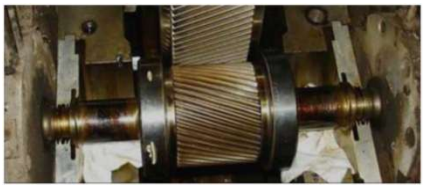
MPC

- Limitation:
  - Gives no indication of the amount of varnish already deposited.
- Interferences:
  - High carbon content from electrostatic spark discharge or micro-dieseling can skew results.
- Accuracy And Precision:
  - Results are evaluated against an arbitrary scale of 0-100, repeatability is highly subjective to age of sample at time of testing.

402

MPC - Common Cause

- Oxidation:
  - Generally from higher operating temperatures, higher oil flow rates and/or finer filtration.



403

MPC - Exceptions

- Better Oil Is Not Better In Every Way:
  - Base oil production has trended away from Group I oils (lower purity, higher solvency) toward Group II and III (higher purity, lower solvency):
    - In some cases less varnish is produced, but a greater percentage plates out and is therefore not detected in the sample

404

MPC - Pitfalls

- Riding A See-Saw:
  - A high result simply means the fluid contains varnish and the system may still be relatively clean, but a low result could indicate most of the produced varnish has plated out and problems exist.
- Correlation:
  - MPC does not correlate with AN, RPVOT or RULER.

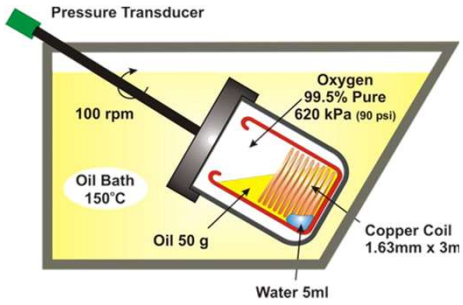
405

Rotating Pressure Vessel Oxidation Test (RPVOT)

- Application:
  - Used in large volume systems; turbine, hydraulic, compressor.
- Principle:
  - The oxidative stability of the sample is measured in the presence of water, copper catalyst, oxygen and heat.
  - Trending results (measured in minutes) can determine the remaining useful life.

406

RPVOT



407

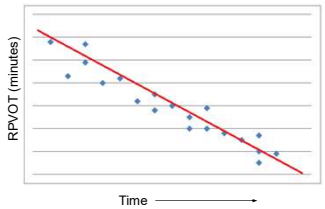
RPVOT

- Limitations:
  - Procedure evaluated on steam turbine oils with results <1000 minutes.
  - Sample must have anti-oxidant additive.
  - Time intensive and expensive test.
- Interferences:
  - No significant interferences.
- Accuracy And Precision:
  - For samples with results from 30-1000 min.
    - Repeatability: < 12% 19 times out of 20.
    - Reproducibility: < 22% 19 times out of 20.

408

RPVOT - Common Cause

- Oxidation Inhibitor Depletion:
  - Trending values allow determination of remaining useful life.



409

RPVOT - Exceptions

- Sudden Drop OK When New:
  - Some oils, particularly those ~600 minutes when new, will have dramatic drop in values for the first few samples but then become very stable changing by only a few minutes per month later.

410

RPVOT - Pitfalls

- Always Trend:
  - Absolute values often result in early change-outs, trend to determine an oil change approximately 3 months before achieving a zero minute result.

411

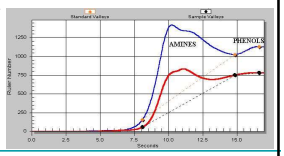
RULER®

- Application:
  - Used in turbine applications to measure remaining antioxidant level (Remaining Useful Life Evaluation Routine) - hindered phenols and aromatic amines.
- Principle:
  - Sample is mixed with an electrolytic test solution, the instrument applies a voltage, the antioxidants will become chemically excited and create an oxidation current. Oxidation current is plotted against voltage, creating a voltammogram, which is compared to reference oil.

412

RULER®

- Limitation:
  - Single result does not necessarily indicate imminent concern.
- Interferences:
  - None
- Accuracy And Precision:
  - Repeatability: <0.7779 $(x+2)^{0.5}$%.
  - Reproducibility: <1.830$(x+2)^{0.5}$%.



413

RULER® - Pitfalls

- Riding A See-Saw:
  - A high result simply means the fluid still has active antioxidants and the system may still be relatively clean, but a low result only means there is little antioxidant left, but not necessarily that any problems exist.
- Correlation:
  - RULER® does not correlate with AN, Viscosity or RPVOT.

414

X-Ray Fluorescence (XRF)

- Application:
  - Samples from components likely to generate large debris not seen by ICP in oil samples, or analysis of debris only samples (i.e. filter patches, spinner material).
- Principle:
  - A beam of X-rays excites a sample, which causes elements within the sample to emit distinctive radiation back to a detector.

415

XRF

- Limitations:
  - Spinner Debris / Filter Patch.
    - No detection of some additives/contaminants (Na, B, P, K, Be, Cd, S, Cl).
  - Oil Samples:
    - Be, Na, B not detected.
  - See particles above 5 micron that ICP can't.
- Interferences:
  - No significant interferences.

416

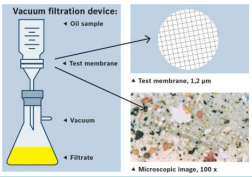
XRF

- Accuracy And Precision:
  - Spinner Debris / Filter Patch: Semi-Quantitative.
  - Oil Samples: Quantitative.
- Rules Of Thumb:
  - Spinner Debris: Routine testing to trend.
  - Filter Patch: Trigger test from unacceptable or severe ISO or OPC.
  - Oil Sample: Trigger test from unacceptable or severe ISO or OPC, or routine on high value equipment.
- Pitfalls:
  - High particulate (>5 µm) may not correlate against spectrometric results (0-5 µm).

417

Filter Analysis

- Application:
  - Data bank of the wear and contamination history.
- Principle:
  - A portion of filter is back-flushed, the solution is filtered onto a patch and analyzed qualitatively under a microscope.



418

Filter Analysis

- Limitation:
  - Only analyzes particles down to pore size of filter, oil itself will need to be analyzed to see everything.
- Interferences:
  - No significant interferences.
- Accuracy And Precision:
  - Reasonably good at identifying what is present, but due to its subjective nature, quantification may vary.

419

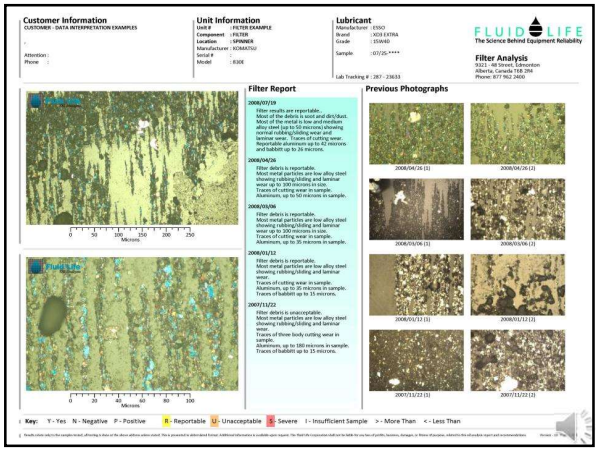
Filter Analysis

- Rules Of Thumb:
  - Look at every filter when changing, test those that seem abnormal.
  - Cut open filter and backflush. Then look at particles using XRF.
- Pitfalls:
  - Debris accumulates over life of filter, significant results do not necessarily mean occurrence was recent or excessive.

420

Filter Analysis Example

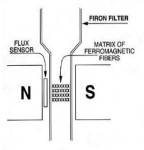
421



422

Total Magnetic Iron

- Application:
  - Samples from components likely to generate large debris; gearbox, final drive or transmission.
- Principle:
  - Magnets are used to quantify ferrous particulate, in ppm.
- Limitations:
  - Does not measure non-ferrous metals.
  - Does not identify type of metal found.



423

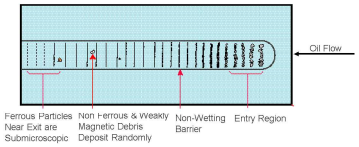
Total Magnetic Iron

- Interferences:
  - No significant interferences.
- Accuracy And Precision:
  - Gains accuracy with increasing results.
- Rules Of Thumb:
  - Use increasing trend to trigger Ferrography.
- Pitfalls:
  - Failure to use test as screening tool to reduce frequency of analytical ferrography, also included in ferrography.

424

Analytical Ferrography

- Application:
  - Any sample as a diagnostic and forensic tool.
- Principle:
  - A slide is produced with the aid of magnets to separate wear debris and arrange according to size. A microscope is used to identify type and generating wear mode.



425

Analytical Ferrography

- Slides are heat treated to oxidize material and change its color for identification purposes.
- Referred to as a bichromatic microscope because it can use top and bottom light to look at the material on the slide.

426

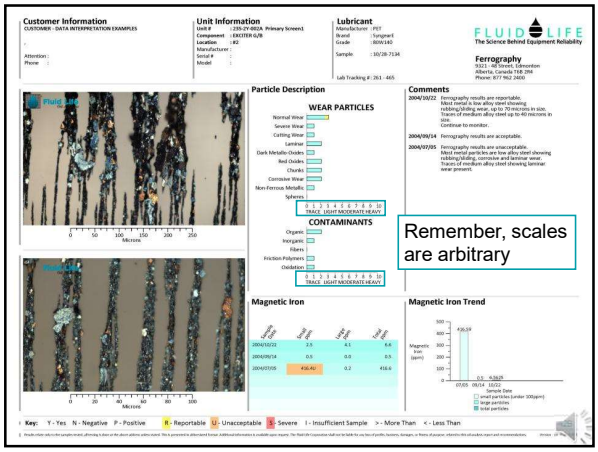
Analytical Ferrography

- Limitation:
  - Interpretation is based on skill and experience of analyst.
- Interferences:
  - No significant interferences.
- Accuracy And Precision:
  - Excellent at identifying what is present, but quantification is subjective.
- Rules Of Thumb:
  - Do not limit this test to post-failure analysis only, useful for trending.
- Pitfalls:
  - One test on its own does not always give a clear picture.
  - Analyst selects rating of sample on a scale of 1 - 10.

427

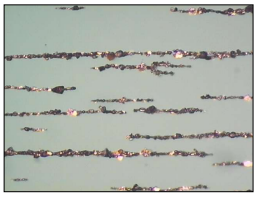
Analytical Ferrography Example

428



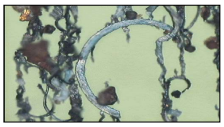
429

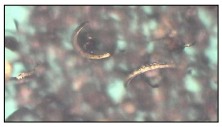
Ferrography - Adhesive Wear

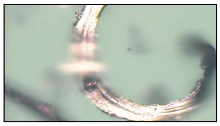



430

Ferrography - Cutting Wear


Low Alloy Steel


Copper Alloy

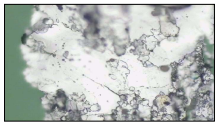

High Alloy Steel

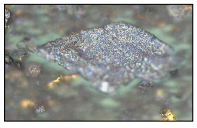
431

Ferrography - Bearing Metal Wear


Copper Alloy

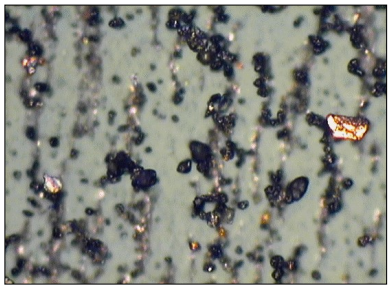

Low Alloy Steel


Steel Prior to Heat Treatment


Lead/Tin Babbitt Metal

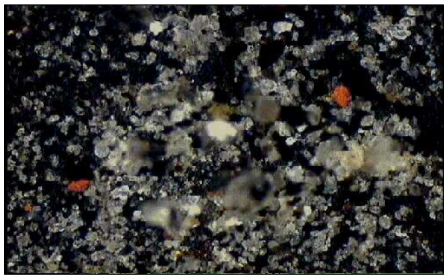
432

Ferrography - Black Oxides



433

Ferrography - Sand and Dirt



UNDER POLARIZED LIGHT

434

Ferrography - Fibers

Without Polarized Light

With Polarized Light

435

Agenda

- Fundamentals of Lubricants
- Contamination Sources and Control Strategies
- Oil Sampling Basics
- Sample Registration
- **Data Interpretation**
  - Overview of Data Interpretation
  - Categories of testing
  - **Establishing Limits**

436

Establishing Limits

- OEM Limits
- Oil Company Limits
- Industry Limits
- Laboratory Limits
- Customer Goal-Specific Limits

437

OEM Limits - Mobile Equipment

- Most OEMs of mobile equipment (Caterpillar, Komatsu, Deere, Hitachi, etc.) have proprietary oil analysis limits, but some publish "typical" wear rates.

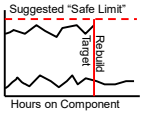
Obsolete Caterpillar "Suggested Safe Wear Levels"
ppm = parts per million

	Diesel Engine	Transmissions	Hydraulics	Final Drives/Differentials
Silicon	5-20 ppm	5-30 ppm	1-10 ppm	25-75 ppm
Iron	10-80 ppm	10-100 ppm	1-15 ppm	50-300 ppm
Chromium	2-10 ppm	1-4 ppm	1-3 ppm	2-6 ppm
Aluminum	4-15 ppm	6-10 ppm	1-10 ppm	30-100 ppm
Copper	10-30 ppm	20-250 ppm	1-20 ppm	
Sodium	10-50 ppm	10-50 ppm		
Lead	5-30 ppm			
Tin	5-30 ppm			

438

OEM Limits - Mobile Equipment

- Manufacturers use these limits to:
  - Highlight necessary repairs.
  - Deal with warranty claims.
- Should be considered a starting point only.
- If goal includes component life extension, system should be maintained well under these levels.



439

OEM Limits - Hydraulics

- OEMs publish "recommended" cleanliness levels.
- Exceeding these limits may lead to much shorter component life, however, this does not always indicate an immediate failure.
- Always examine ISO particle count results with wear metal analysis.

440

Hydraulics Cleanliness Targets

Steps to setting the appropriate Fluid Cleanliness Level:

- **Step 1:**
  - Select the ISO Recommended Cleanliness Code from the OEM, or other sources based on equipment and service.
  - Example: 5000 psi system with variable piston pump, servo valve and high speed journal bearing.
- **Step 2:**
  - If the fluid is not 100% petroleum oil, adjust the code down one level cleaner.

441

Hydraulic Cleanliness Targets

Steps to setting the appropriate Fluid Cleanliness Level:

- **Step 3:**
  - If any of the following conditions apply, set the target code one level cleaner:
    - Frequent cold starts at < -18°C (0°F).
    - Intermittent operation with fluid temperatures > 70°C (158°F).
    - High vibration or high shock operation.
    - Critical dependence on the system as a part of a process operation.
    - Personal safety of employees that could be put at risk by a system malfunction.

442

OEM Limits - ISO Particle Counts

PUMPS	<2000 PSI	2000 - 3000 PSI	>3000 PSI
Fixed Gear	20/18/15	19/17/15	
Fixed Vane	20/18/15	19/17/14	18/16/13
Fixed Piston	19/17/15	18/16/14	17/15/13
Variable Vane	18/16/14	17/15/13	
Variable Piston	18/16/14	17/15/13	16/14/12
VALVES		**<3000 PSI**	**>3000 PSI**
Directional (Solenoid)		20/18/15	19/17/14
Pressure Control (Modulating)		19/17/14	19/17/14
Flow Controls (Standard)		19/17/14	19/17/14
Proportional Directional (Throttle Valves)		17/15/12	15/13/11
Check Valves		20/18/15	20/18/15
Servo Valves		16/14/11	15/13/10
Cartridge Valves		18/16/13	17/15/12
H.R.C.		18/16/13	17/15/12
Proportional Pressure Controls		16/14/12	15/13/11
Flow Controls		17/15/13	17/15/13
Proportional Cartridge Valves		17/15/12	16/14/11

ACTUATORS	<2000 PSI	2000-3000 PSI	>3000 PSI
Cylinders	20/18/15	20/18/15	20/18/15
Vane Motors	20/18/15	19/17/14	18/16/13
Axial Piston Motors	19/17/14	18/16/13	17/15/12
Gear Motors	21/19/17	20/18/15	19/17/14
Radial Piston Motors	20/18/14	19/17/13	18/16/13
Cam Wave Motors	18/16/14	17/15/13	16/14/12
HYDROSTATIC TRANSMISSIONS	**<3000 PSI**	**3000 - 4000 PSI**	**>4000 PSI**
Hydrostatic Transmissions	17/15/13	16/14/12	16/14/11
BEARINGS			
Ball Bearing Systems	15/13/11		
Roller Bearing Systems	16/14/12		
Journal Bearings (High Speed)	17/15/13		
Journal Bearings (Low Speed)	18/16/14		
General Industrial Gearboxes	17/15/13		

443

Viscosity Condemning Limits

- SAE 40 in a Four-Stroke Diesel Engine

MANUFACTURER	MAXIMUM 100 °C VISCOSITY	MINIMUM 100 °C VISCOSITY
Detroit Diesel	>25 cSt	<12.5 cSt
Imperial Oil	+25% from new	-20% from new
Caterpillar	+3 cSt from new	-3 cSt from new
Fluid Life[1]	≥16.3 cSt	<12.5 cSt

Fluid Life follows the SAE J300 grading system for viscosity flagging

444

Water Condemning Limits

- According to Detroit Diesel, water content as low as 500 ppm (0.05%) can seriously affect the oil's filterability and additive function:
  - Condemn at 3000 ppm (0.3%).
- According to Caterpillar water occurs as a natural consequence of combustion and can reach the point of emulsibility:
  - Condemn at 5000 ppm (0.5%).

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Oil Company Limits

- Limits established for the physical and chemical properties of the oil.
- Used to identify products (MSDS sheets).
- Additive levels change constantly as oil chemistry changes.
- These limits are used to identify mixtures of oils, incorrect oil, etc.

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Laboratory Limits

- Most laboratories set their flagging limits using:
  - Absolute Limits:
    - Statistical Analysis.
    - Knowledge of equipment.
    - User-specified limits.
  - Rate-of-Wear Limits:
    - Wear Factor.
    - % Increase.

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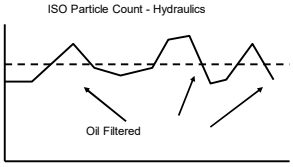
Absolute Limits - Pros

- Pros:
  - Absolute limits are appealing to commercial labs.
  - Computerized flagging speeds up:
    - Data interpretation & sample turnaround.
    - When limit is exceeded, action is required.



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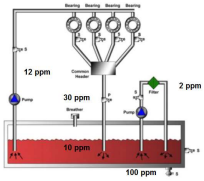
Absolute Limits - Cons

- Consistent sampling location must be used.
- Absolute limits will vary from point to point.
- Inform the lab of where sample was taken for proper interpretation.



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Custom Alarm Limits

- Why do customers need to set their own custom flagging limits for their specific equipment and operating conditions?
  - The following table shows the recommended flagging limits for lead (Pb) based on data from 5 different customers with the same engine model.
    - Alarm points are based on the 95%, 98% and 99% distribution curve of their individual sample results.
    - Minimum of 500 sample results at each location.

Customer	Reportable	Unacceptable	Severe
#1	8	25	42
#2	9	14	26
#3	12	21	37
#4	14	22	61
#5	18	29	40

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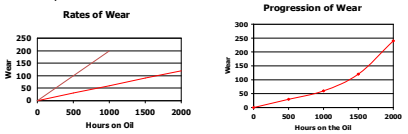
Rate of Change Limits

- As oil is left in service, wear particles will increase steadily.
- However, the rate at which particles are generated is much more important to detecting failure modes.
- Wear rate is calculated by examining the slope of the graph (rise/run).



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What is the right answer?

- Certain failure modes can be missed by relying on absolute limits alone.
- Incorrect assumptions are often made when using rate-of-change limits.
- Should combine:
  - Statistically derived alarm limits, customer specific if possible.
  - Rate-of-change limits, make and model specific, even customer specific if possible.
  - OEM limits, when available.
  - Lube supplier limits, when available.

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