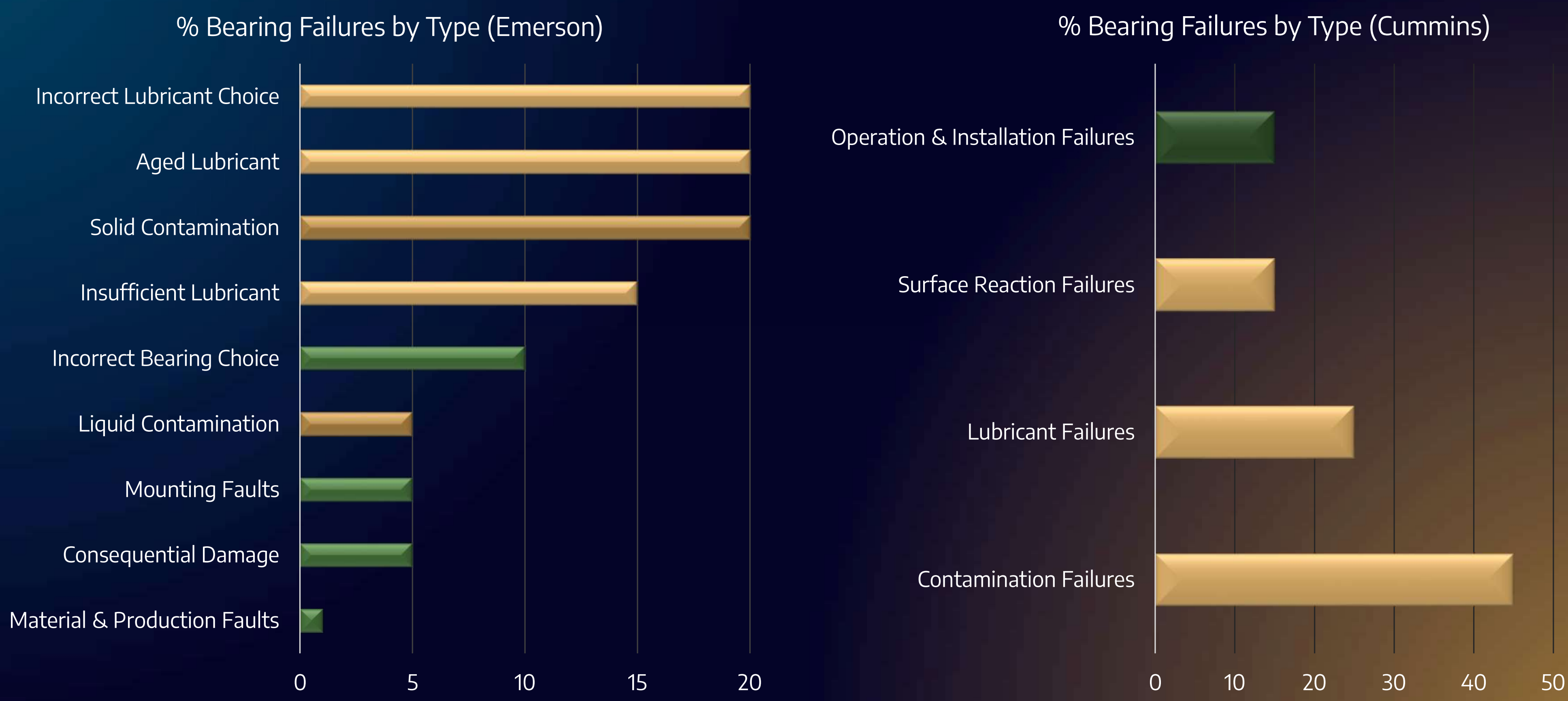
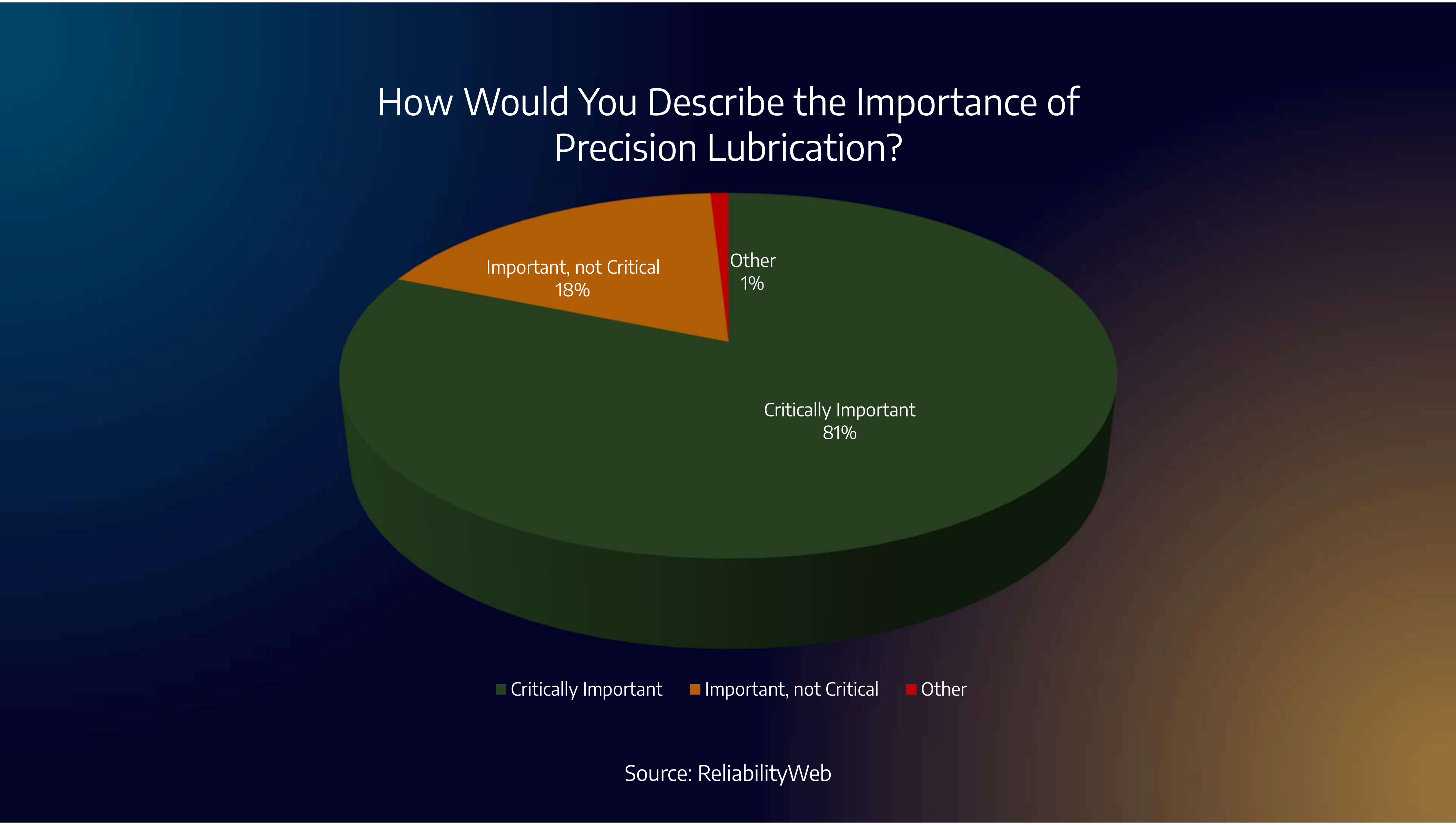
Lubrication Explained

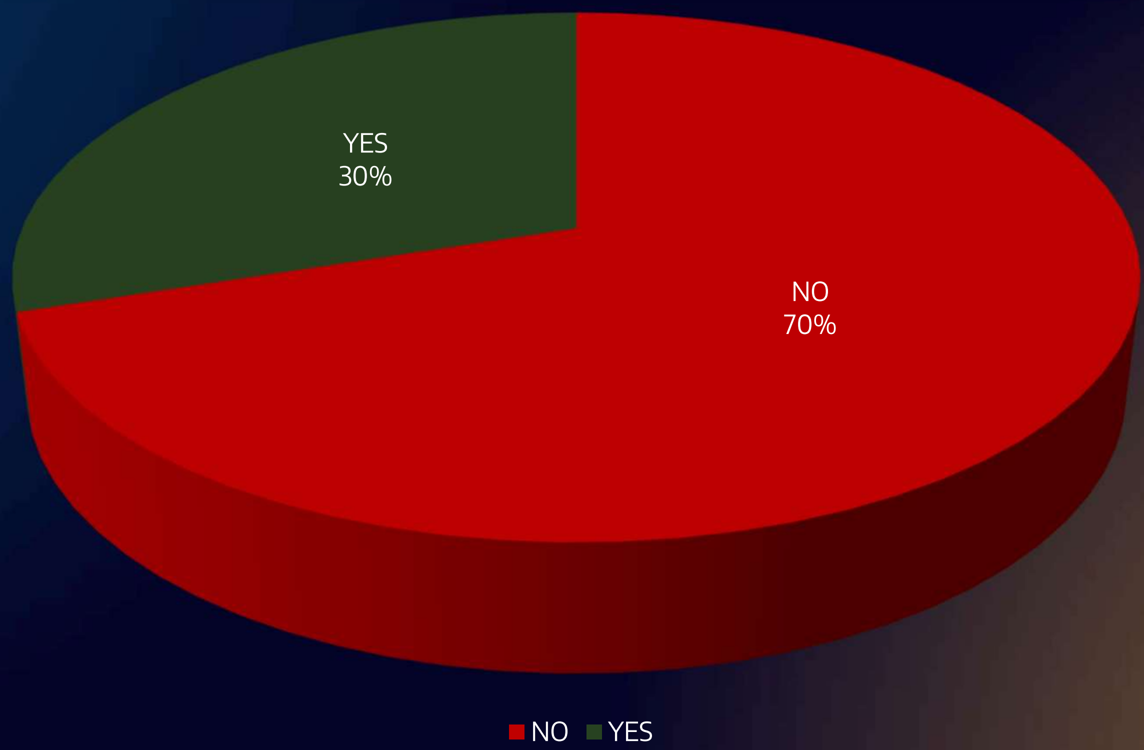
Lubrication Experts

Lubricants and Lubrication as a Path to Reliability




How Would You Describe the Importance of Precision Lubrication?
Important, not Critical
18%
Other
1%
Critically Important
81%
Critically Important
Important, not Critical
Other
Source: ReliabilityWeb

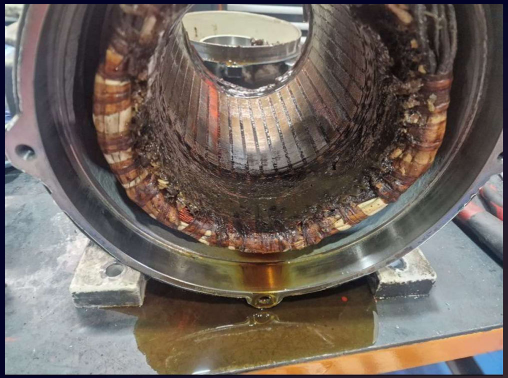
Have you achieved a level of lubrication that you would consider close to best practice?



Source: ReliabilityWeb

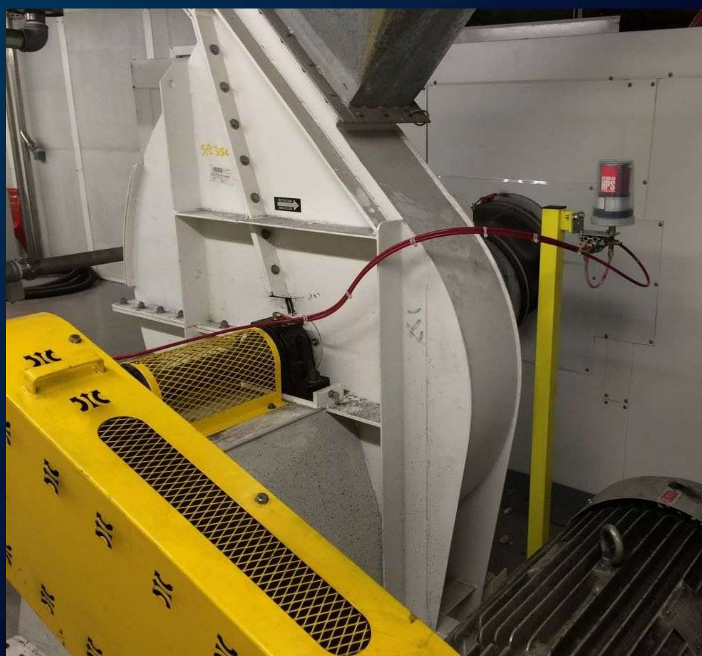
The Main Issues That I See in the Field

Courtesy Simon Murray



Courtesy Matt Fletcher

The Main Issues That I See in the Field



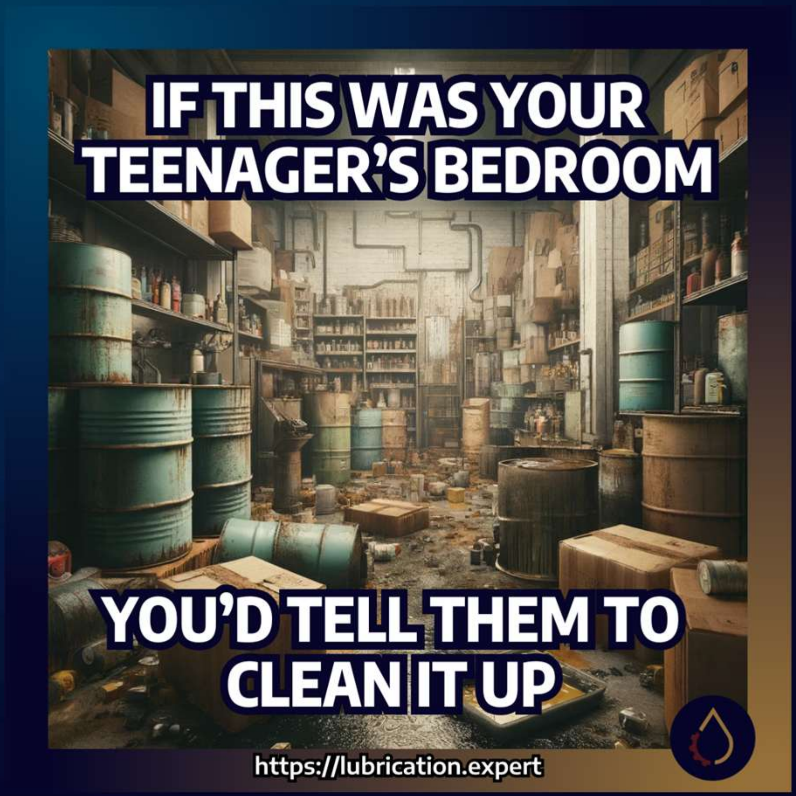
When running long lines – confirm that the bearing is actually receiving grease.

One of the dangers of SPLs is their "set and forget" nature. We tend to set, then forget!

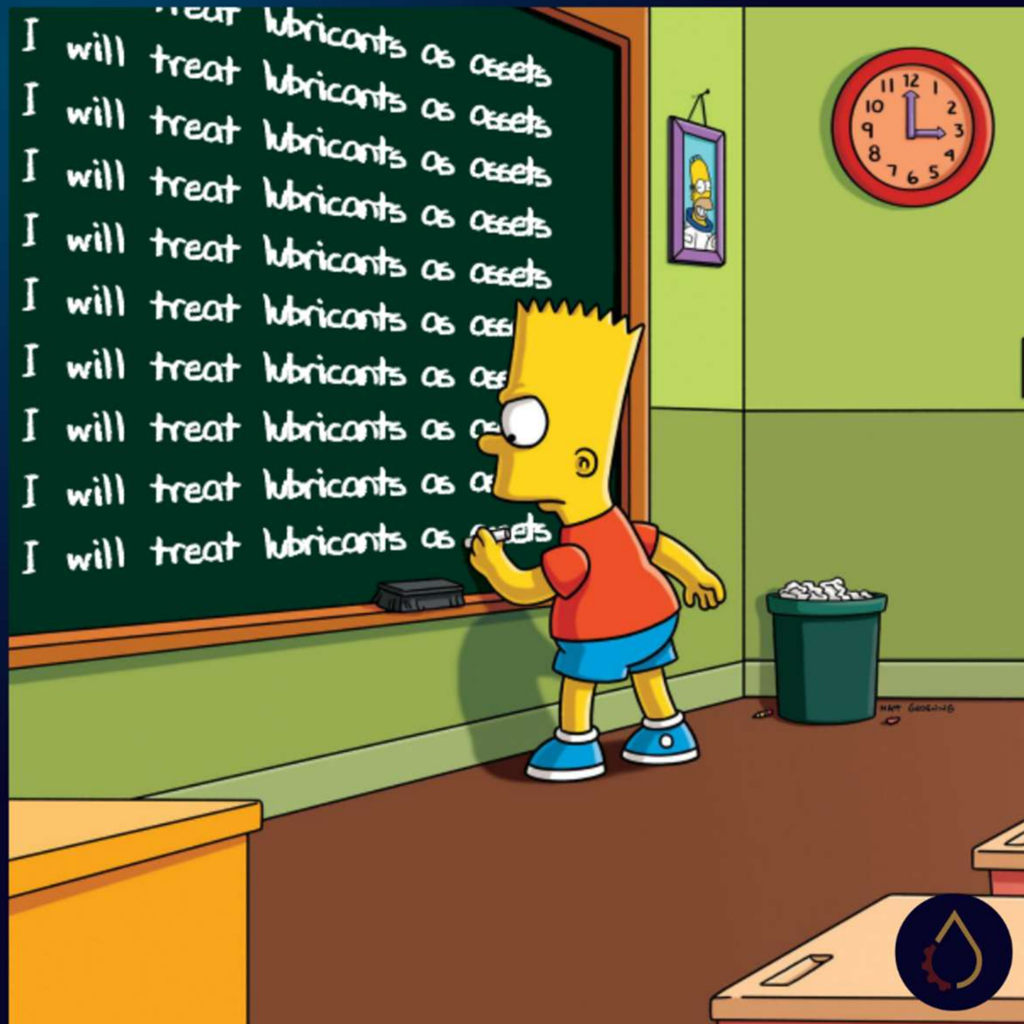
The Main Issues That I See in the Field

Product sourcing issues

Poor Storage and Contamination Control



Video courtesy of Greg Romer
(Hydrocarbon Program Consultancy)


I will treat lubricants as assets
I will treat lubricants as assets
I will treat lubricants as assets
I will treat lubricants as assets
I will treat lubricants as assets

Lubricant

Lubricant

Lubricant

Lubricant

Lubricant

Use of Lubricant

Lubricant

Lubricant

Use of Lubricant

Lubricant Analysis

Lubricants

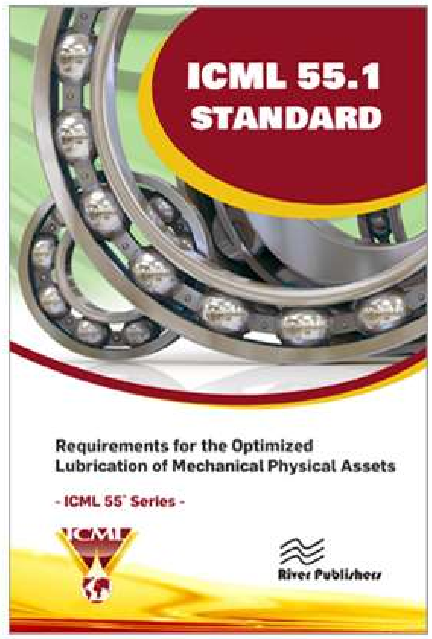
Lubrication

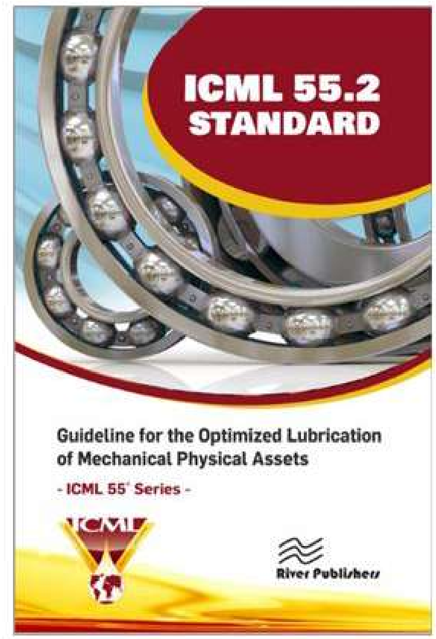
Lubricant Analysis

Lubricants	Lubrication	Lubricant Analysis
Machine	Operate & Maintain	Data

Lubricants	Lubrication	Lubricant Analysis
Machine	Lubrication	Lubricant Analysis
	Operate & Maintain	Data

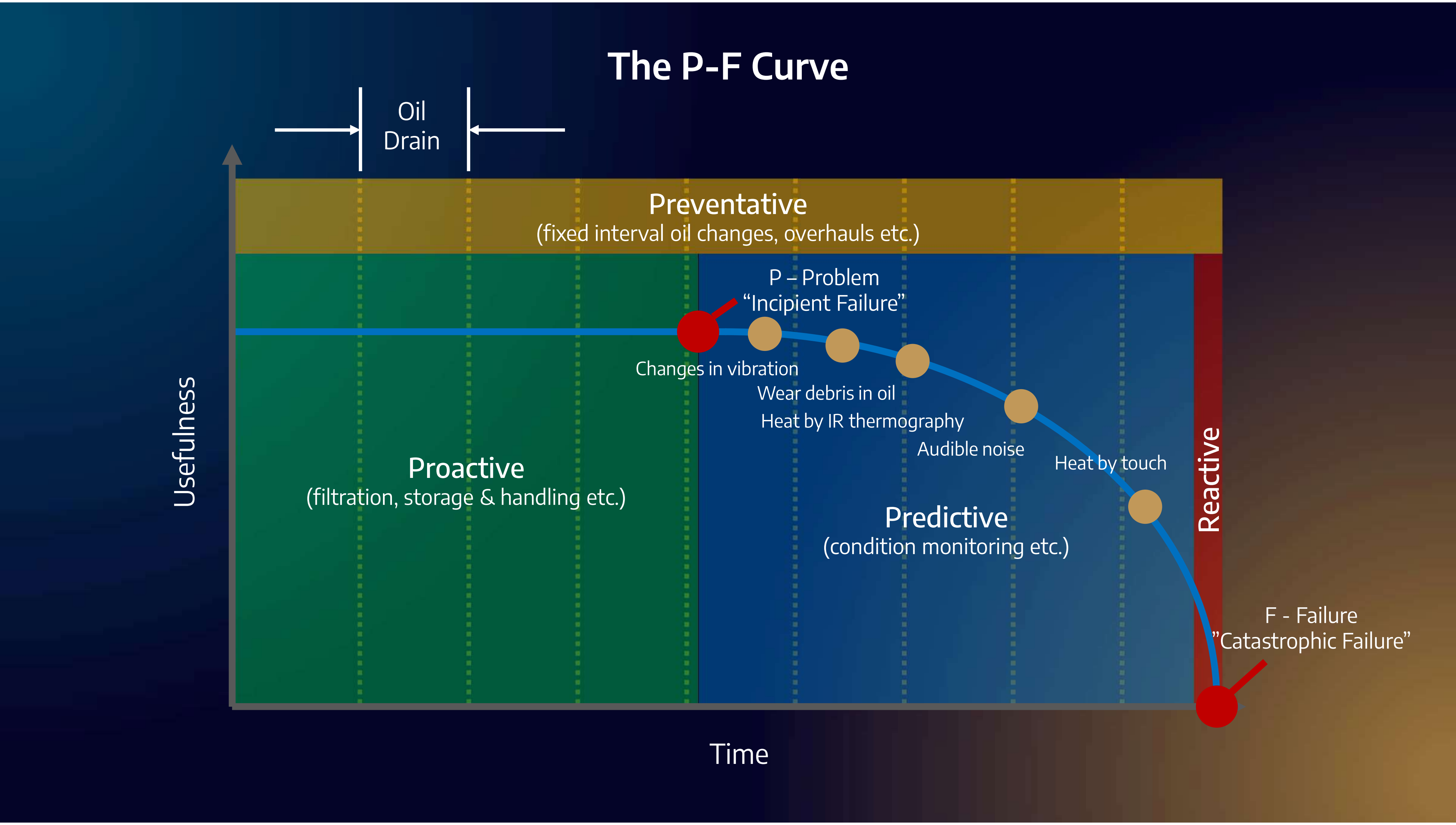

ICML 55.0
STANDARD
Optimized Lubrication of Mechanical Physical Assets Overview
- ICML 55® Series -
ICML
River Publishers


ICML 55.1
STANDARD
Requirements for the Optimized Lubrication of Mechanical Physical Assets
- ICML 55® Series -
ICML
River Publishers


ICML 55.2
STANDARD
Guideline for the Optimized Lubrication of Mechanical Physical Assets
- ICML 55® Series -
ICML
River Publishers


Select
Detect
Inspect
Protect
Connect
Reflect


Select
Detect
Inspect
Protect
Connect
Reflect


The P-F Curve
Oil
Drain
Preventative
(fixed interval oil changes, overhauls etc.)
P – Problem
“Incipient Failure”
Changes in vibration
Wear debris in oil
Heat by IR thermography
Audible noise
Heat by touch
Proactive
(filtration, storage & handling etc.)
Predictive
(condition monitoring etc.)
Reactive
Usefulness
F - Failure
”Catastrophic Failure”
Time

Maintenance Types

Reactive

"Fix it when it breaks"

"Change the oil with the asset"

Preventative

"Fix it at pre-determined intervals"

"Change oil in the gearbox once every six months"

Predictive

"Fix it when the problem is sensed"

"Oil analysis identifying wear particles"

Proactive

"Fix the root cause before the problem event"

"Defining target ISO cleanliness codes for new oils on site"

Lubricant Application

Manual Regreasing

Lever-style manual grease guns can exert 15,000psi – far exceeding the rating of most bearing seals and having the potential to cause serious injury. They should be treated like any high-pressure hydraulic equipment would be.

Manual grease guns should be calibrated (grams per shot).

The newer, battery-operated units can be just as dangerous. While easier on the arms, they give no feedback when pressure is increasing.

“The M18™ Cordless 2-Speed Grease Gun delivers maximum pressure and unmatched versatility, offering an industry leading 10,000 PSI max operating pressure and a patent pending pre-set grease counter that allows service and maintenance professionals to dispense precise amounts of grease."

Manual calculation using bearing OEM calculators, or standard methods (example below).

$$Q_g = k_g \times C_d \times \pi \times d \times b$$

- Q_g = Grease volume per hour
- k_g = Rotation speed factor (see table below)
- C_d = Diametrical clearance
- π = 3.14
- d = Shaft diameter
- b = Bearing width

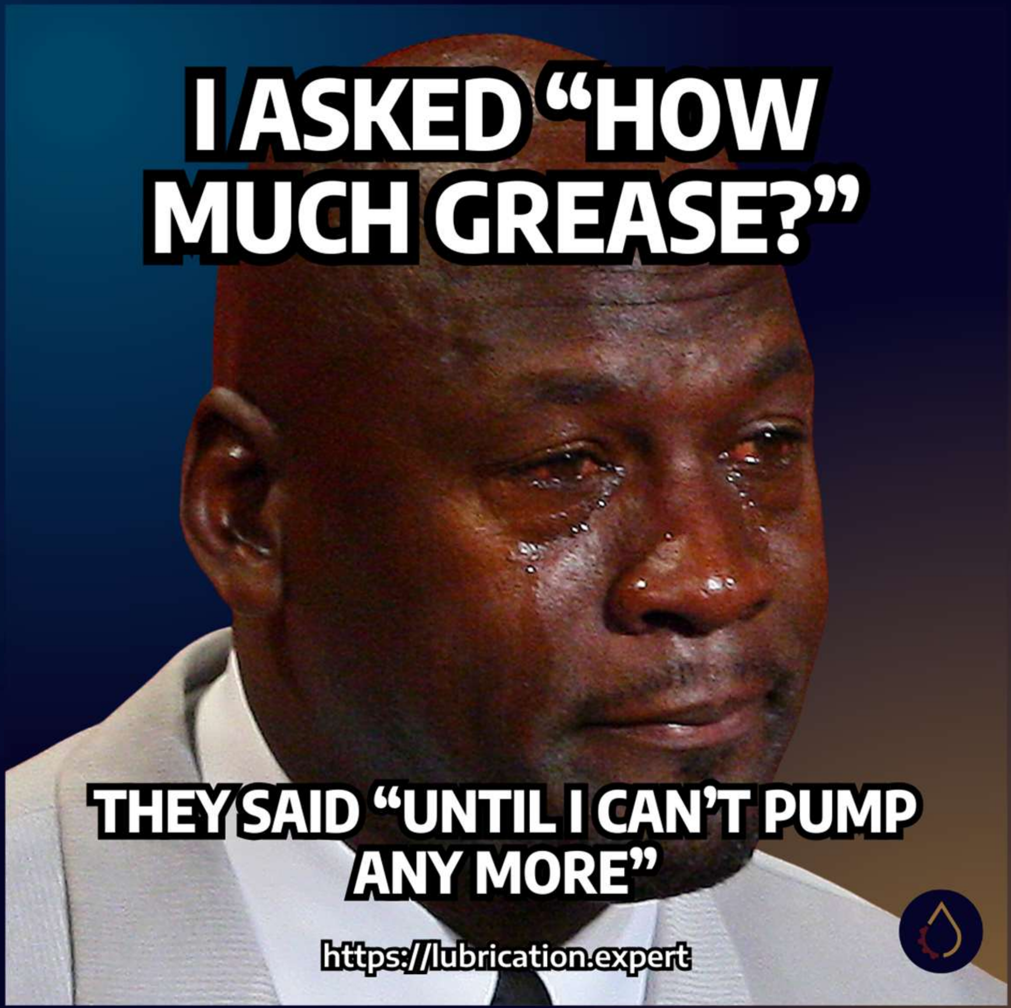
The Rotation Speed Factor term can be determined via the following shaft speed ranges:

Shaft Speed (rev/min)	k_g
Up to 100	0.1
101 - 250	0.2
251 - 500	0.4
501 - 1000	1

Manual Regreasing Best Practices

- Calibrate grease guns
- Clean the grease nipple/port with a lint-free rag
- Clean the end of the grease gun with a lint-free rag
- Regrease with the volume according to the work instructions, stopping if there is significant resistance
- Replace the grease fitting cap (if it is there – which is unlikely). If there is no cap, put some grease over the fitting to prevent contamination.
- Depressurise the grease gun
- Record the volume of grease pumped, and the date for each grease point
- Make note of anything unusual (noise, heat etc)

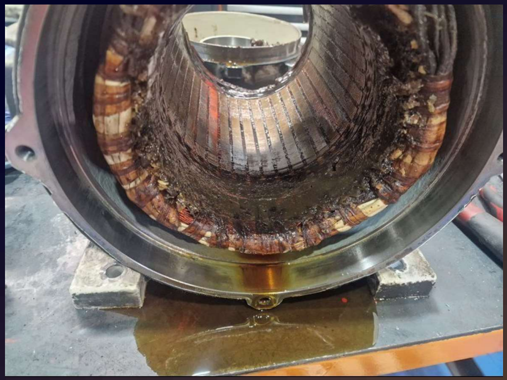
WHY ARE WE REGREASING?


I ASKED "HOW MUCH GREASE?"
THEY SAID "UNTIL I CAN'T PUMP ANY MORE"
https://lubrication.expert

Consequences of Over and Under Greasing

Over-Greasing:

- Causes heat build-up, bearing seal damage, clean-up issues, and downtime.
- Surplus grease forces rollers/balls to slide instead of roll, churning grease aside.
- Increased friction and pressure separate oil from thickener, hardening grease and reducing lubrication.
- Can damage seals, allowing water and dirt contamination.



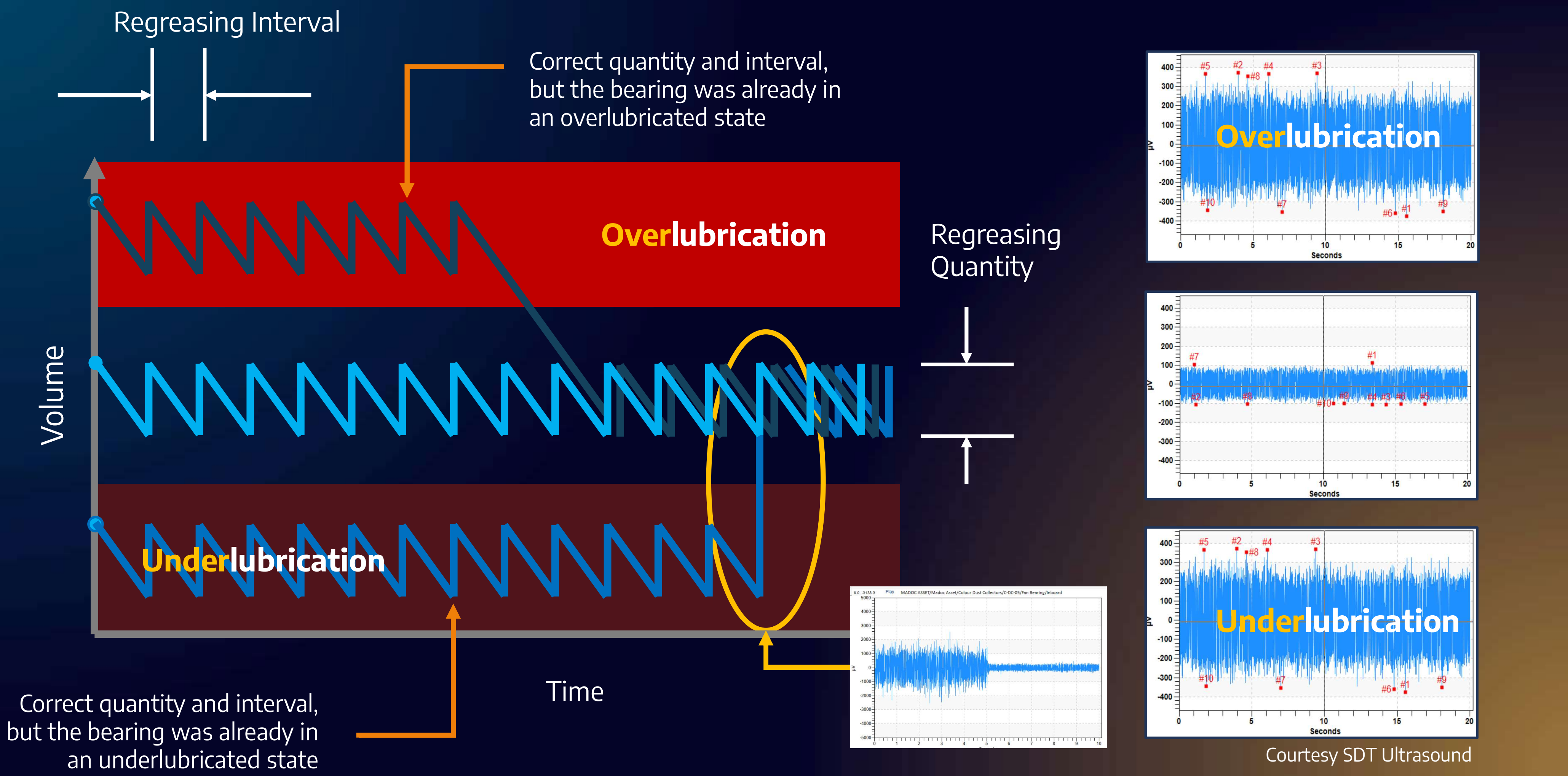
Electric motor overgreasing

Under-Greasing:

- Leads to insufficient lubrication, increasing friction and heat.
- Makes contamination more likely, causing damage to rotating parts.
- Remaining grease oxidises and hardens, reducing effectiveness..

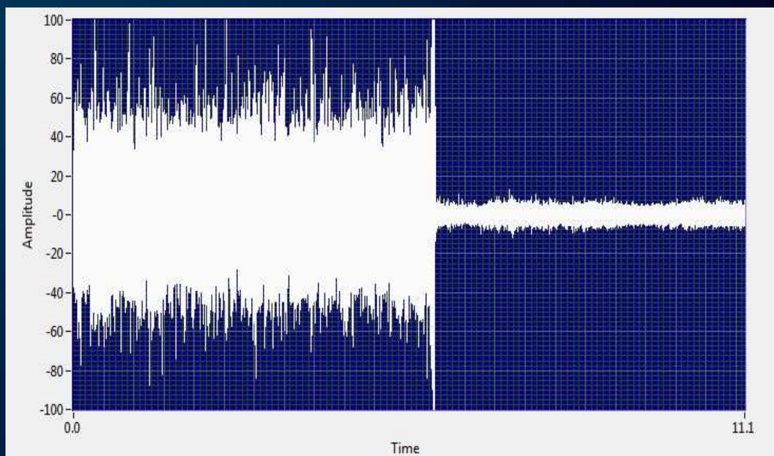
SO HOW DO YOU CALCULATE THE CORRECT AMOUNT OF GREASE?

Condition Based Greasing (Ultrasonics)

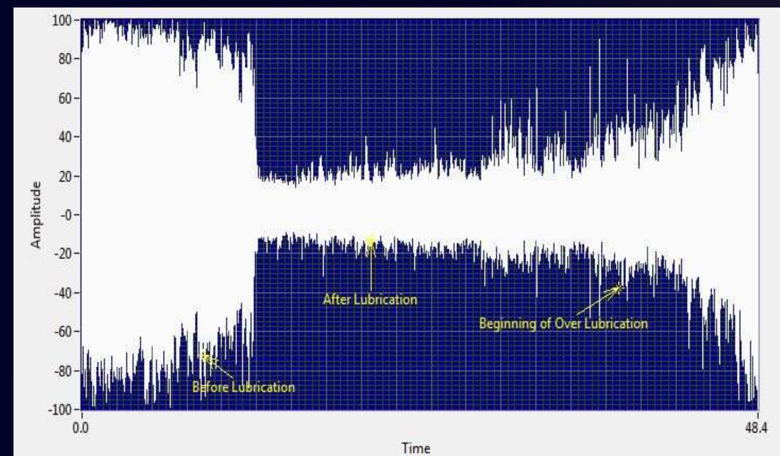


Courtesy SDT Ultrasound

Condition Based Greasing (Ultrasonics)



Bearing in the process of being greased. Note the before lubrication on the left, and then after lubrication on the right

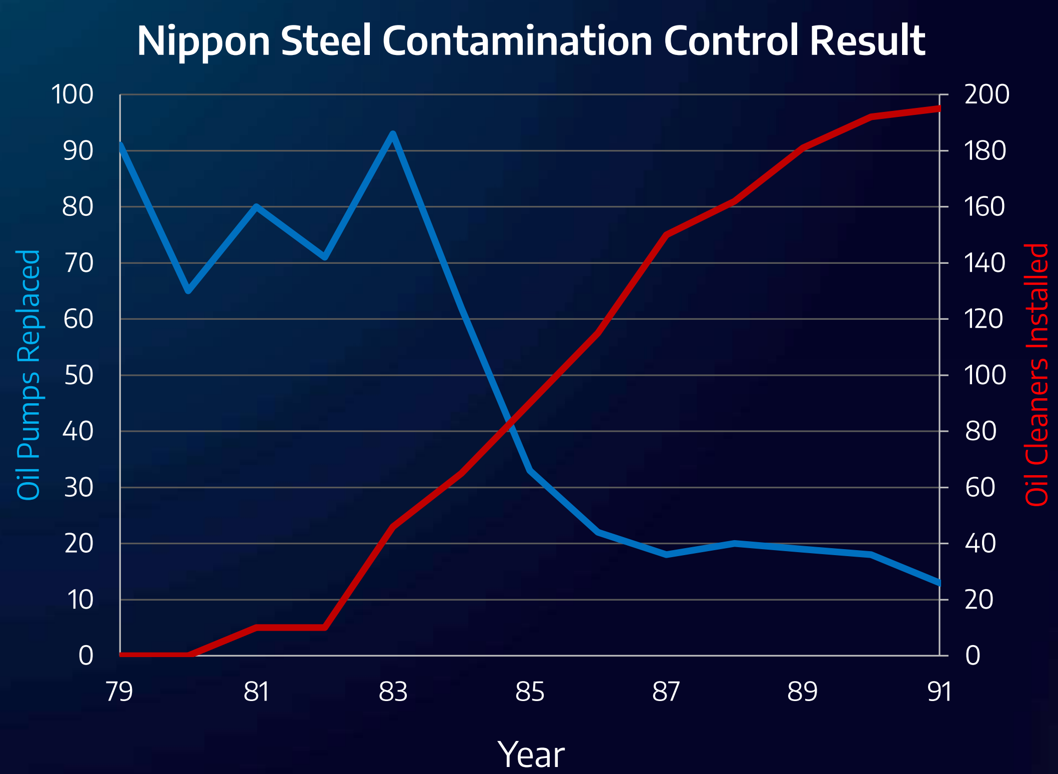


Bearing in the process of being greased, but too much grease was added. Note the before lubrication on the left, the point where they should have stopped, and what happens when too much grease is added.

Courtesy UE Systems

Cleanliness

The Importance of Contamination Control



Source: NIPPON STEEL & SUMITOMO METAL TECHNICAL REPORT No. 112 APRIL 2016

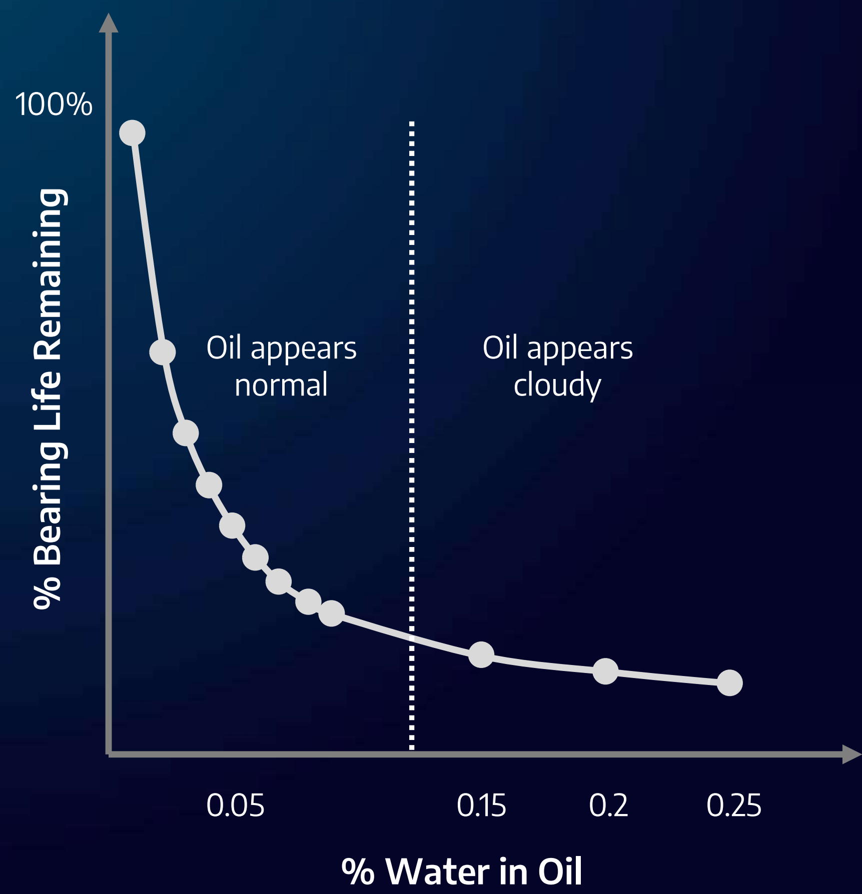
"... bearings can attain a much longer life than predicted by normal life calculation methods. These special conditions are when the rolling surfaces are effectively separated by a lubricant film and when the surface damage caused by contaminants is limited. In fact, under ideal conditions, it is possible to speak of infinite life"

- Bearing Maintenance Handbook, SKF

"Proper selection and placement of contamination control devices in a system to attain the targeted cleanliness eliminates (the root cause of) up to 80% of hydraulic system failures"

- Systematic Approach to Contamination Control, Vickers Inc

The Effect of Water on Bearing Life



Asset Life Extension Table

New Moisture Level (ppm)

Current Moisture Level (ppm)	10,000		5,000		2,500		1,000		500		250		100	
50,000	2.5	5	3	7	3.5	9	4	>10	5	>10	6.5	>10	7	>10
25,000	2	4	2.5	5	3	7	3.5	9	4	>10	5	>10	6	>10
10,000	1.5	3	2	4	2.5	6	3	7	4	9	5	>10	6	>10
5,000	1.3	2	1.5	3	2	4	2.5	5	3	7	3.5	9	4	>10
2,500	1.1	1.6	1.3	2	1.7	3	2	4	2.5	5	3	7	3.5	8
1,000	1.1	1.3	1.3	1.5	1.4	2	1.6	3	2	4	2.5	5	3	7
500			1.05	1.3	1.3	1.6	1.4	2	1.7	3	2	4	2.5	5
250					1.1	1.3	1.3	1.6	1.5	2	1.7	3	2	4
100							1.1	1.3	1.3	1.6	1.5	2	1.7	3

Source: Noria & SKF

Rolling Element Bearings   Plain Bearings

Asset Life Extension via Contamination Control

New ISO Cleanliness Code

Current ISO Cleanliness Code

	22/20/17		21/19/26		20/18/15		19/17/14		18/16/13		17/15/12		16/14/11		15/13/10		14/12/9		13/11/8		12/10/7	
28/26/23	2.5	5	3	7	3.5	9	4	>10	5	>10	6.5	>10	7	>10	9	>10	10	>10	>10	>10	>10	>10
27/25/22	2	4	2.5	5	3	7	3.5	9	4	>10	5	>10	6	>10	7.5	>10	9	>10	>10	>10	>10	>10
26/24/21	1.5	3	2	4	2.5	6	3	7	4	9	5	>10	6	>10	7	>10	8	>10	10	>10	>10	>10
25/23/20	1.3	2	1.5	3	2	4	2.5	5	3	7	3.5	9	4	>10	5	>10	6.5	>10	8.5	>10	10	>10
24/22/19	1.1	1.6	1.3	2	1.7	3	2	4	2.5	5	3	7	3.5	8	4	>10	5	>10	5.5	>10	8.5	>10
23/21/18	1.1	1.3	1.3	1.5	1.4	2	1.6	3	2	4	2.5	5	3	7	3.5	9	4	>10	5.5	>10	8	>10
22/20/17			1.05	1.3	1.3	1.6	1.4	2	1.7	3	2	4	2.5	5	3	7	4	9	5.5	>10	7	>10
21/19/16					1.1	1.3	1.3	1.6	1.5	2	1.7	3	2	4	2.5	5	3.5	7	4.5	9	6	>10
20/18/15							1.1	1.3	1.3	1.6	1.5	2	1.7	3	2	4	2.5	5	3.7	7	5	>10
19/17/14									1.1	1.3	1.3	1.6	1.5	2	1.7	3	2	4	2.5	6	3.5	8
18/16/13											1.1	1.3	1.3	1.6	1.5	2	1.8	3	3	4	3.5	6
17/15/12													1.1	1.3	1.4	1.6	1.5	2	1.8	3	2.2	4
16/14/11															1.2	1.3	1.4	1.6	1.5	2	1.8	3
15/13/10																	1.1	1.4	1.3	1.8	1.6	2.5

Source: Noria Corporation

Hydraulics

Gears

Asset Life Extension via Contamination Control

New ISO Cleanliness Code

Current ISO Cleanliness Code	22/20/17		21/19/26		20/18/15		19/17/14		18/16/13		17/15/12		16/14/11		15/13/10		14/12/9		13/11/8		12/10/7	
28/26/23	2.5	5	3	7	3.5	9	4	>10	5	>10	6.5	>10	7	>10	9	>10	10	>10	>10	>10	>10	>10
27/25/22	2	4	2.5	5	3	7	3.5	9	4	>10	5	>10	6	>10	7.5	>10	9	>10	>10	>10	>10	>10
26/24/21	1.5	3	2	4	2.5	6	3	7	4	9	5	>10	6	>10	7	>10	8	>10	10	>10	>10	>10
25/23/20	1.3	2	1.5	3	2	4	2.5	5	3	7	3.5	9	4	>10	5	>10	6.5	>10	8.5	>10	10	>10
24/22/19	1.1	1.6	1.3	2	1.7	3	2	4	2.5	5	3	7	3.5	8	4	>10	5	>10	5.5	>10	8.5	>10
23/21/18	1.1	1.3	1.3	1.5	1.4	2	1.6	3	2	4	2.5	5	3	7	3.5	9	4	>10	5.5	>10	8	>10
22/20/17			1.05	1.3	1.3	1.6	1.4	2	1.7	3	2	4	2.5	5	3	7	4	9	5.5	>10	7	>10
21/19/16					1.1	1.3	1.3	1.6	1.5	2	1.7	3	2	4	2.5	5	3.5	7	4.5	9	6	>10
20/18/15							1.1	1.3	1.3	1.6	1.5	2	1.7	3	2	4	2.5	5	3.7	7	5	>10
19/17/14									1.1	1.3	1.3	1.6	1.5	2	1.7	3	2	4	2.5	6	3.5	8
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Source: Noria Corporation

Hydraulics

Gears

Asset Life Extension via Contamination Control

New ISO Cleanliness Code

Current ISO Cleanliness Code

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28/26/23	2.5	5	3	7	3.5	9	4	>10	5	>10	6.5	>10	7	>10	9	>10	10	>10	>10	>10	>10	>10
27/25/22	2	4	2.5	5	3	7	3.5	9	4	>10	5	>10	6	>10	7.5	>10	9	>10	>10	>10	>10	>10
26/24/21	1.5	3	2	4	2.5	6	3	7	4	9	5	>10	6	>10	7	>10	8	>10	10	>10	>10	>10
25/23/20	1.3	2	1.5	3	2	4	2.5	5	3	7	3.5	9	4	>10	5	>10	6.5	>10	8.5	>10	10	>10
24/22/19	1.1	1.6	1.3	2	1.7	3	2	4	2.5	5	3	7	3.5	8	4	>10	5	>10	5.5	>10	8.5	>10
23/21/18	1.1	1.3	1.3	1.5	1.4	2	1.6	3	2	4	2.5	5	3	7	3.5	9	4	>10	5.5	>10	8	>10
22/20/17			1.05	1.3	1.3	1.6	1.4	2	1.7	3	2	4	2.5	5	3	7	4	9	5.5	>10	7	>10
21/19/16					1.1	1.3	1.3	1.6	1.5	2	1.7	3	2	4	2.5	5	3.5	7	4.5	9	6	>10
20/18/15							1.1	1.3	1.3	1.6	1.5	2	1.7	3	2	4	2.5	5	3.7	7	5	>10
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28/26/23	4	3	4.5	3.5	6	6	6.5	5	7.5	6	8.5	7.5	10	9	>10	>10	>10	>10	>10	>10	>10	>10
27/25/22	3	2.5	3.3	3	4.5	4.5	5	4	6.5	5	8	6	9	7	10	9	>10	>10	>10	>10	>10	>10
26/24/21	2.5	2	3	2.5	4	4	5	4	6.5	5	7.5	6	8.5	7	9.5	8	>10	10	>10	>10	>10	>10
25/23/20	1.7	1.5	2.3	2	3	3	3.7	3	5	3.5	6	4	7	5	8	6	9.5	8	>10	9	>10	>10
24/22/19	1.4	1.3	1.8	1.5	2.3	2.3	3	2.5	3.5	3	4.5	3.5	5.5	4	7	5	8	6	10	7	>10	>10
23/21/18	1.2	1.2	1.5	1.5	1.8	1.8	2.2	2	3	2.5	3.5	3	4.5	3.5	5	4	7	5	9	7	10	10
22/20/17			1.2	1.2	1.5	1.5	1.8	1.7	2.3	2	3	2.5	3.5	3	5	4	5	5	8	7	10	9
21/19/16					1.2	1.2	1.5	1.5	1.8	1.7	2.2	2	3	2.5	3.5	3	5	4	7	6	9	8
20/18/15							1.2	1.2	1.5	1.5	1.8	1.7	2.3	2	3	2.5	3.5	3	5.5	4.5	8	6
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17/15/12													1.2	1.2	1.5	1.5	1.8	1.7	2.3	2	3	2.5
16/14/11															1.3	1.3	1.6	1.6	1.9	1.8	2.3	2
15/13/10																	1.2	1.2	1.6	1.5	2	1.8

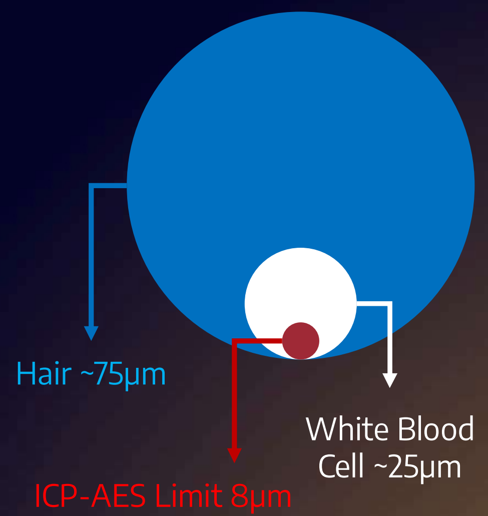
Source: Noria Corporation

Rolling Element Bearings

Plain Bearings

Typical Oil Film Thickness

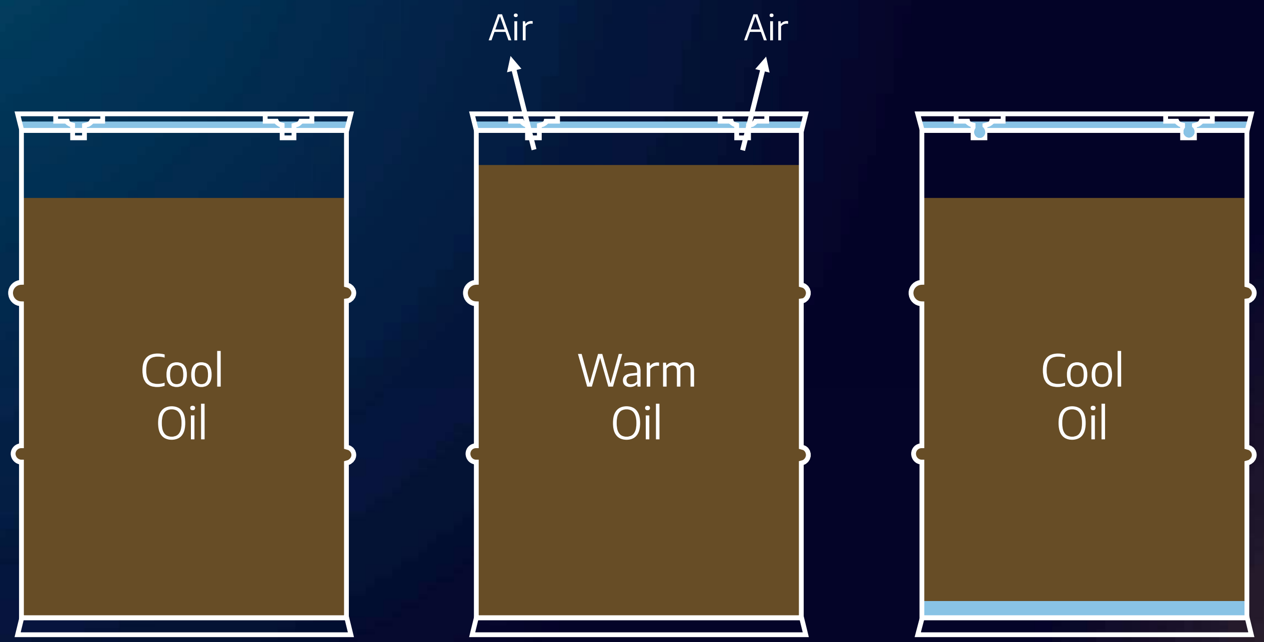
Roller bearing	0.1 to 1 µm
Ball bearing	0.4 to 0.7 µm
Journal bearing	0.5 to 25 µm
Hydrostatic bearing	5 to 100 µm
Gears	0.1 to 1 µm
Dynamic seal	0.05 to 0.5 µm
Vane pump	0.5 to 13 µm
Hydraulic piston pump	0.5 to 450 µm
Hydraulic servo valves	1 to 450 µm
Hydraulic actuators	130 to 450 µm



Key takeaway: damaging contaminants are invisible to the naked eye. Contaminants in the 0.1 – 10 µm range are incredibly damaging to equipment.

IS NEW OIL CLEAN?

How Drums “Breathe"



Video courtesy of Greg Romer

Note: the oil isn’t really expanding and contracting this much. It’s the air pressure that is causing the air in the headspace to want to expand and escape, then contract and pull water into the drum.

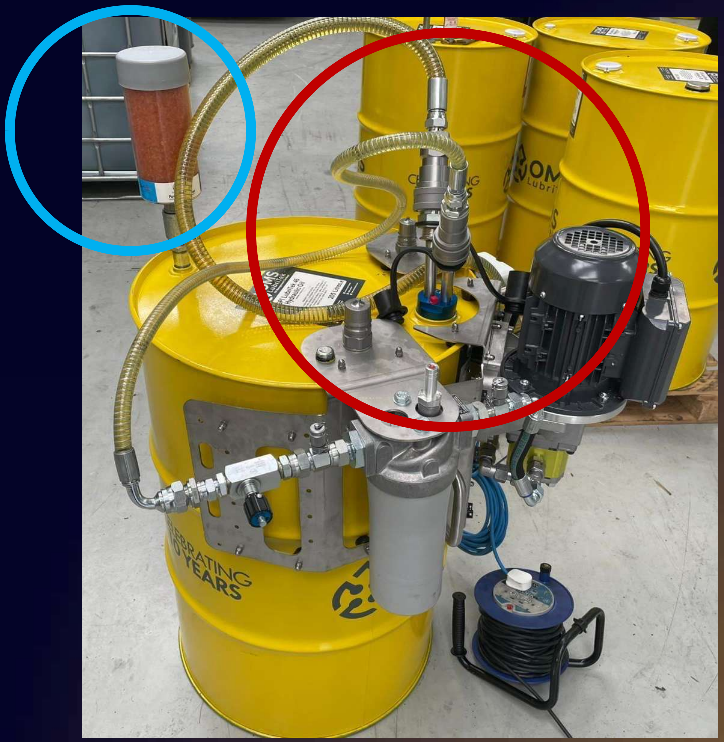
Drum Storage Guidelines

General Principles:

- Store out of the elements
- Store away from direct sunlight
- If stored outdoors, cover drums
- Store them on their side (bungs in 9 o'clock and 3 o'clock position
- Use desiccant breathers to manage moisture
- Use first-in first-out (FIFO) principles of stock management
- Ensure sufficient bunding to manage spills
- Filter to target cleanliness before use
- Filter oil when transferring

Drum Storage Guidelines

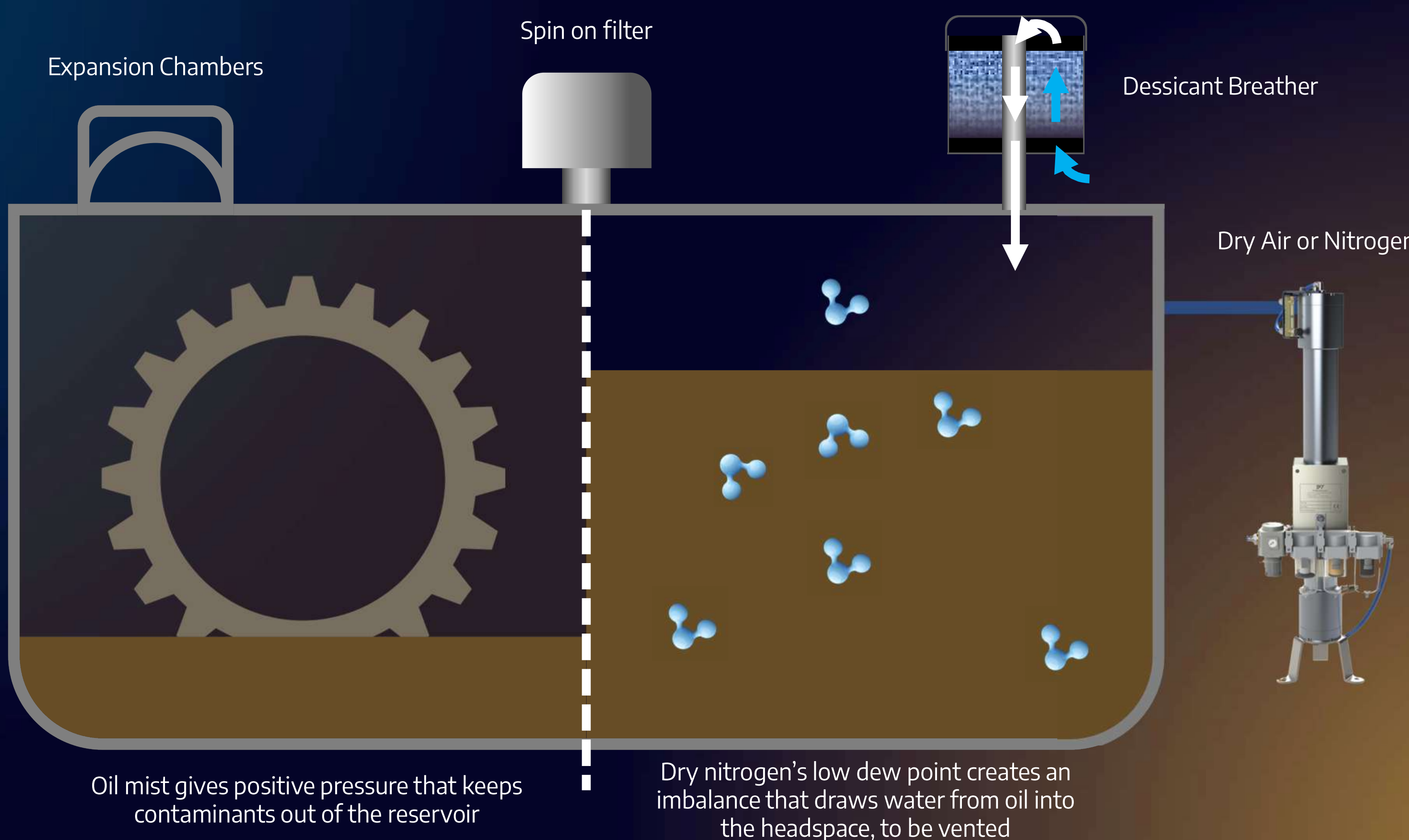
Adapter gives two quick connect fittings and a sampling point for the drum. The spear of one quick connect is short, the other is long to ensure that any filtration will generate flow and the entire drum volume is filtered.



Filtration of new oil to the target cleanliness. Actual cleanliness needs to be verified!

Dessicant breathers ensure that air drawn into the drum is both filtered of particles and moisture.

Headspace Management



Breather Ratings and Selection

Dessicant adsorbs water

Internal oil coalescers stop oil mist from entering breather

Air filter captures fine particulate before it contaminates the oil

Check valves prevent washdown water contacting dessicant. Remove check valves for maximum flow in larger systems

Flow adapter diverts air expelled from reservoir direct to atmosphere, prolonging breather life

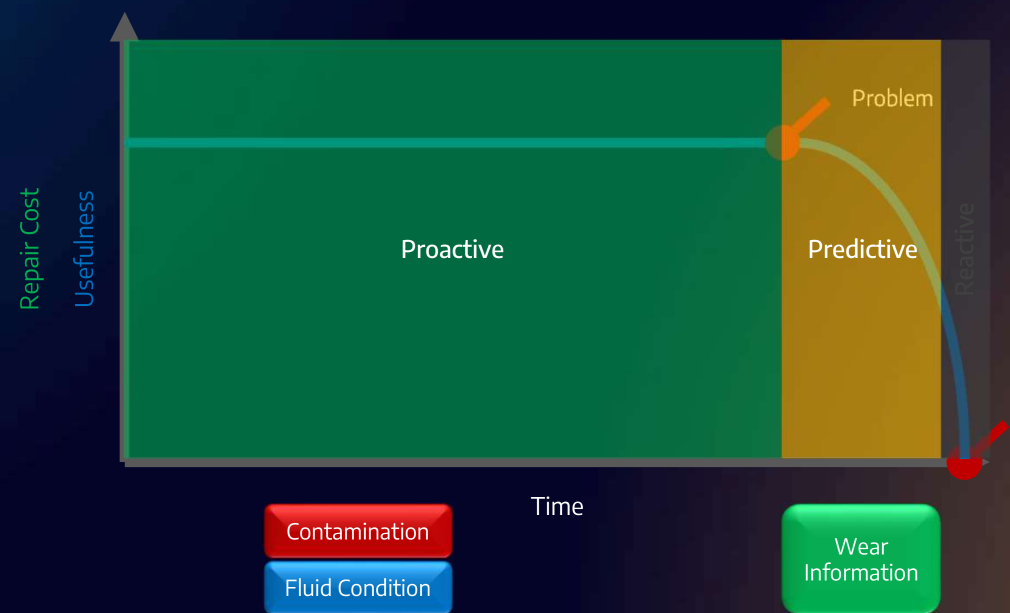
	Removal Efficiency @		
MERV Rating	**0.3–1.0 µm**	**1.0–3.0 µm**	**3–10 µm**
MERV 1	<20%	<20%	<20%
MERV 2	<20%	<20%	<20%
MERV 3	<20%	<20%	<20%
MERV 4	<20%	<20%	<20%
MERV 5	<20%	<20%	20–34%
MERV 6	<20%	<20%	35–49%
MERV 7	<20%	<20%	50–69%
MERV 8	<20%	<20%	70–85%
MERV 9	<20%	<50%	≥85%
MERV 10	<20%	50–64%	≥85%
MERV 11	<20%	65–79%	≥85%
MERV 12	<20%	80–90%	≥90%
MERV 13	<75%	≥90%	≥90%
MERV 14	75–84%	≥90%	≥90%
MERV 15	85–94%	≥95%	≥90%
MERV 16	≥95%	≥95%	≥90%
MERV 17	99.97%	≥99%	≥99%
MERV 18	99.997%	≥99%	≥99%
MERV 19	99.997%	≥99%	≥99%
MERV 20	99.99997%	≥99%	≥99%

Given many oil suppliers do not recommend filtration below 3 microns, this range represents our “last chance” to exclude <3 micron particles from the system.

Used Lubricant Analysis

Oil Analysis Data

Predictive	Proactive
Risk-based	Condition-based
"Fix it when the problem is sensed"	"Fix the root cause before the problem event"



The Importance of Oil Analysis

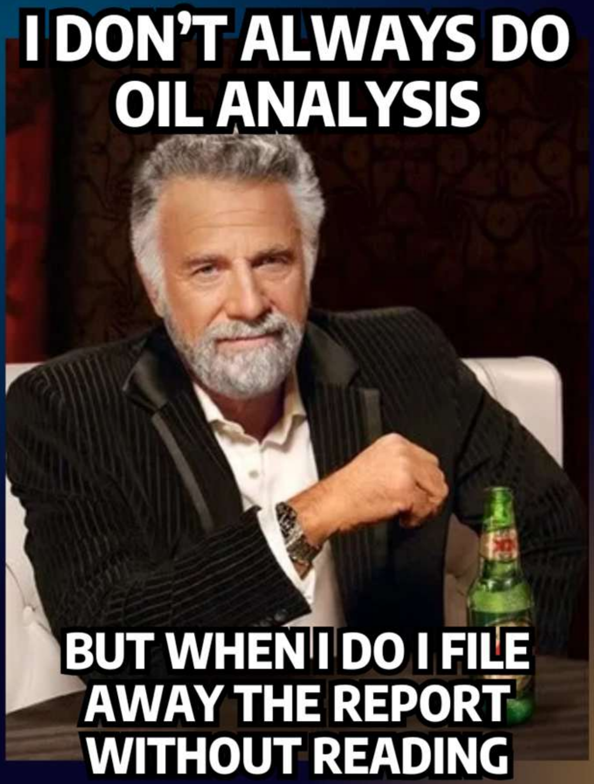
Vibration, ultrasound, and thermography are excellent for detecting advanced or rapidly developing faults (e.g., spalling, misalignment, imbalance), but oil analysis is generally the earliest warning tool for wear mechanisms that start at a microscopic level.

This makes it essential as an early fault detection tool.

Moreover, other condition monitoring tools cannot uncover information about the condition of the oil itself – so oil analysis becomes essential when wanting to understand oil failure modes and the formation of varnish.

The investment in oil analysis usually pays large dividends, but only when every component of the program is adhered to.

Hygienic, representative sampling, combined with accurate testing, quality interpretation, and then action based on those results.



Anatomy of an Oil Analysis Report

Sample information (input by the end user). This is extremely important for trending. Often ignored are details like filter changes, oil top ups and age of the oil.

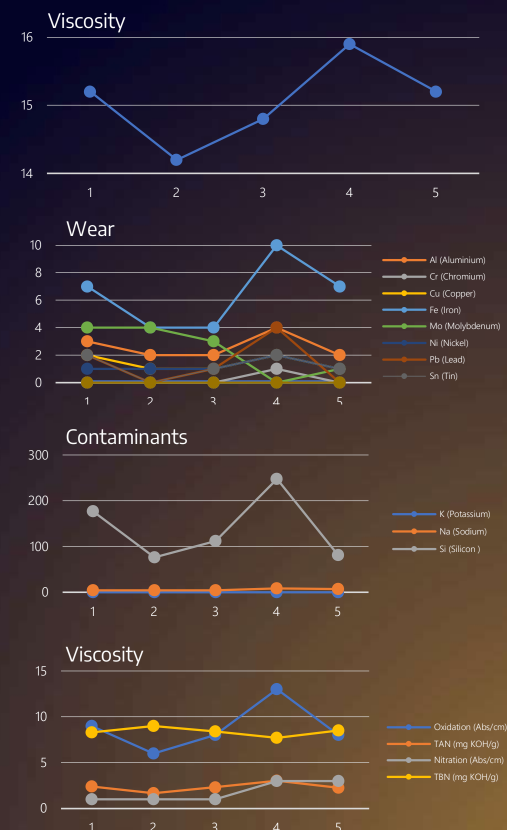
Lubricant condition. Includes information on the oil viscosity, degradation (FTIR oxidation), contaminants (FTIR glycol, soot etc), TAN, TBN.

Wear metals, as determined by ICP

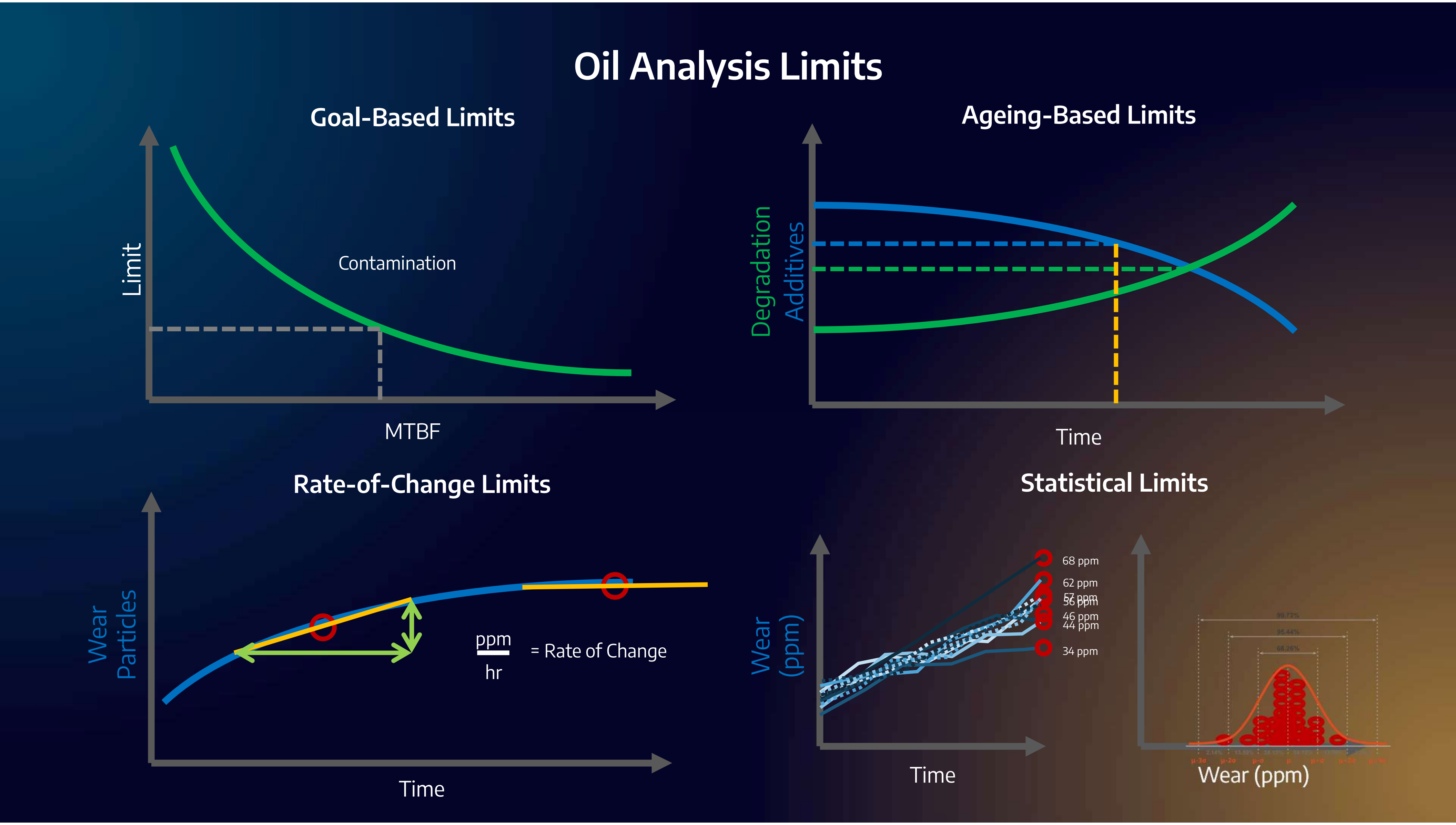
Contaminants, as determined by ICP

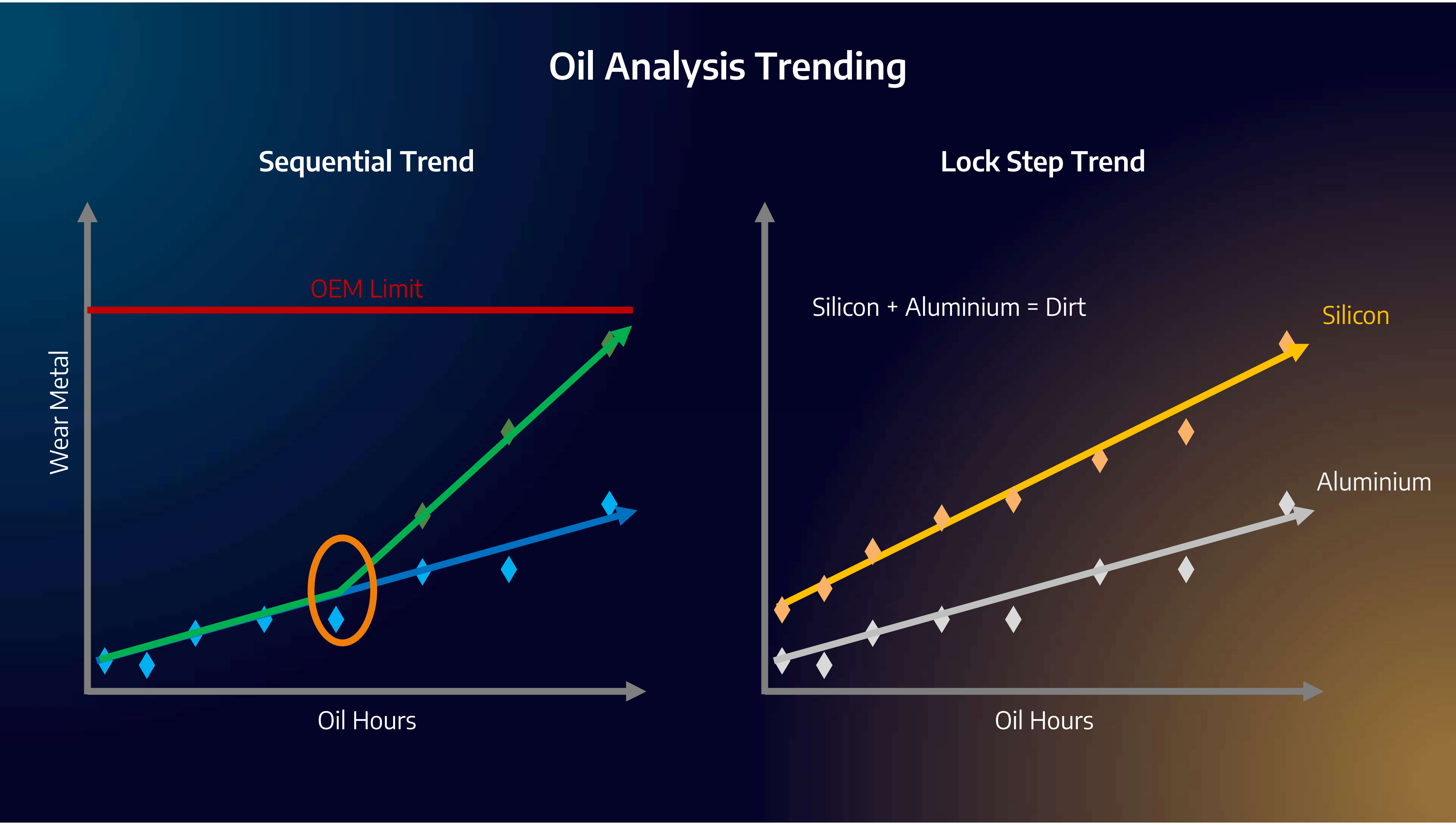
Additives, as determined by ICP

Overall Report Status = NORMAL						
Sample Info	Report Status	Caution	Normal	Normal	Alert	Normal
	Sample ID	156989048	156989060	156989101	156989206	156989348
	Bottle ID	s989048	s89060	s989101	s89206	s989348
	Lubricant	XYZ	XYZ	XYZ	XYZ	XYZ
	Sample Date	09-08-19	09-09-19	09-10-19	09-12-19	09-01-20
	Report Date	19-08-19	19-09-19	19-10-19	19-12-19	19-01-20
	Equipment Age	54206	54300	54758	54862	55001
	Equipment UOM	Hours	Hours	Hours	Hours	Hours
	Oil Changed	Yes	No	No	Yes	No
	Oil Age	486	97	299	525	141
	Oil UOM	Hours	Hours	Hours	Hours	Hours
	Make Up Volume				160	
	Volume UOM				Litres	
	Filter Changed	Yes	No	No	Yes	No
Lubricant	Contamination Rating	Caution	Normal	Normal	Alert	Normal
	Equipment Rating	Normal	Normal	Normal	Normal	Normal
	Oil Rating	Normal	Normal	Normal	Caution	Normal
	PQ Index	1	1	0	5	4
	SAE Grade	40	40	40	40	40
	Visc @100C	15.2	14.2	14.8	15.9	15.2
	Oxidation (Abs/cm)	9	6	8	13	8
	TAN (mg KOH/g)	2.39	1.66	2.31	3.02	2.25
	Nitration (Abs/cm)	1	1	1	3	3
	TBN (mg KOH/g)	8.3	9.0	8.4	7.7	8.5
	Soot (wt%)	0.13	0.11	0.15	0.19	0.19
	Water (vol%)	Not Detected	Not Detected	Not Detected	Not Detected	Not Detected
	Coolant Indicator	Not Detected	Not Detected	Not Detected	Not Detected	Not Detected
	Cl (Cl ppm – Xray)	104	50	85	104	47
Wear (ppm)	Ag (Silver)	0	0	0	0	0
	Al (Aluminium)	3	2	2	4	2
	Cr (Chromium)	0	0	0	1	0
	Cu (Copper)	2	1	1	2	1
	Fe (Iron)	7	4	4	10	7
	Mo (Molybdenum)	4	4	3	0	1
	Ni (Nickel)	1	1	1	2	1
	Pb (Lead)	2	0	1	4	0
	Sn (Tin)	2	0	1	2	1
	Ti (Titanium)	0	0	0	0	0
Contaminant (ppm)	K (Potassium)	0	0	0	0	0
	Na (Sodium)	4	4	4	8	7
	Si (Silicon)	177	76	112	248	81
Additive (ppm)	B (Boron)	1	0	0	1	0
	Ba (Barium)	0	0	0	0	0
	Ca (Calcium)	4085	3914	3790	4379	3767
	Mg (Magnesium)	11	11	11	13	11
	P (Phosphorous)	4	4	3	5	5
	Zn (Zinc)	3	3	3	4	3



HOW DOES THE LAB KNOW WHAT IS AN ADDITIVE, CONTAMINANT, WEAR METAL?

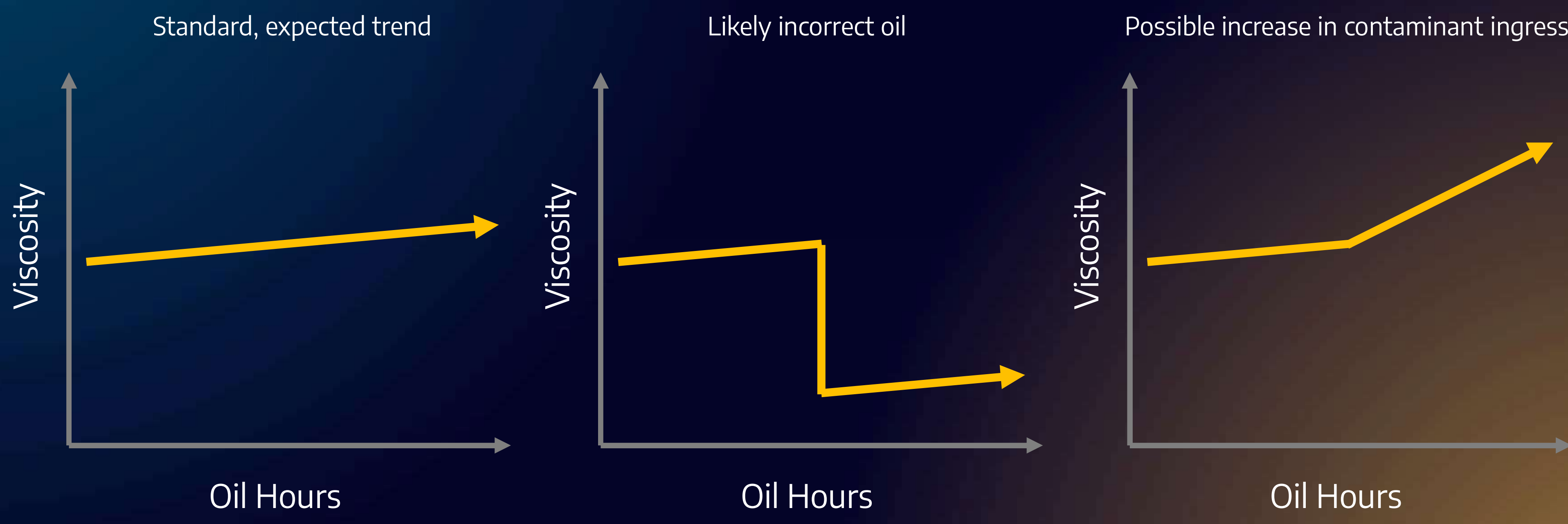

Oil Analysis Limits
Goal-Based Limits
Limit
Contamination
MTBF
Ageing-Based Limits
Degradation
Additives
Time
Rate-of-Change Limits
Wear
Particles
ppm
hr
= Rate of Change
Time
Statistical Limits
Wear
(ppm)
68 ppm
62 ppm
57 ppm
56 ppm
46 ppm
44 ppm
34 ppm
Time
Wear (ppm)

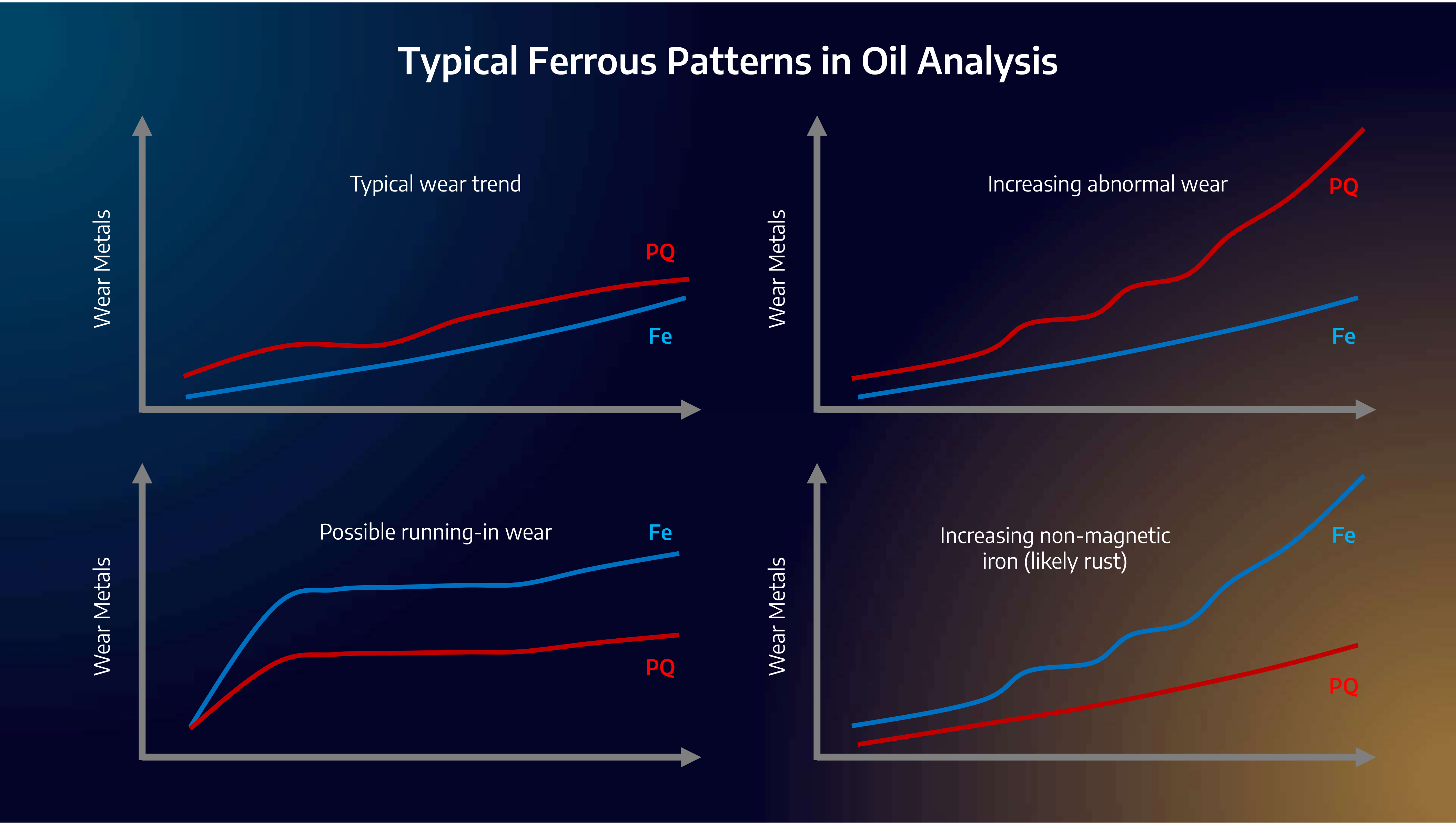

Oil Analysis Trending
Sequential Trend
OEM Limit
Wear Metal
Oil Hours
Lock Step Trend
Silicon + Aluminium = Dirt
Silicon
Aluminium
Oil Hours

Whenever you are reading an oil analysis report, continuously ask yourself a single question:

WHY DO I CARE?!

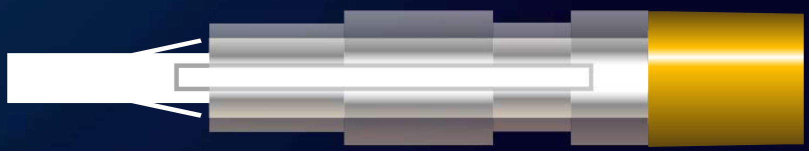
Viscosity Trending

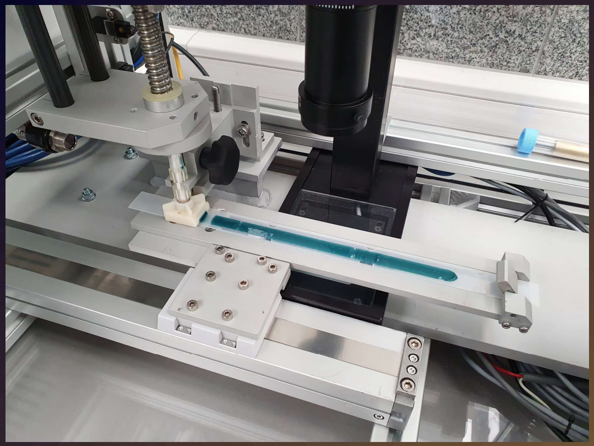



Typical Ferrous Patterns in Oil Analysis
Typical wear trend
Wear Metals
PQ
Fe
Increasing abnormal wear
Wear Metals
PQ
Fe
Possible running-in wear
Wear Metals
Fe
PQ
Increasing non-magnetic
iron (likely rust)
Wear Metals
Fe
PQ


WHO THINKS OIL IS ESSENTIAL TO RELIABILITY?
WHO THINKS GREASE IS ESSENTIAL TO RELIABILITY?
WHO DOES OIL ANALYSIS?
WHO DOES GREASE ANALYSIS?
https://lubrication.expert

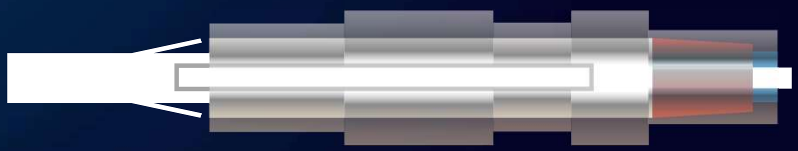
Grease Sampling & Analysis

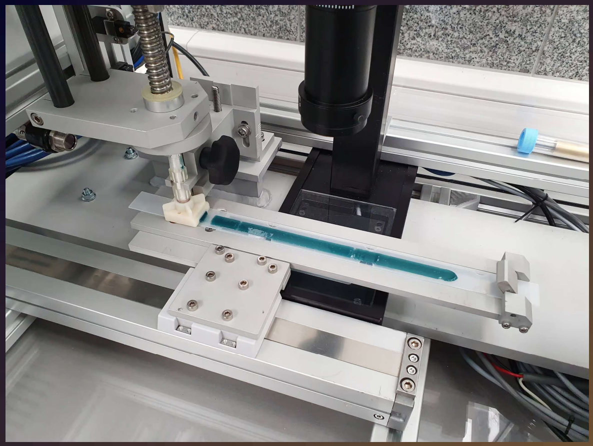




Grease deposited on thin film
Source: Ecol

Grease Sampling & Analysis





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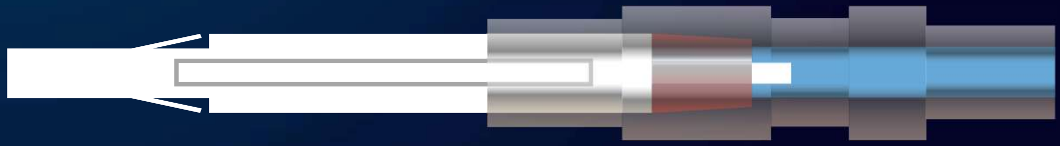

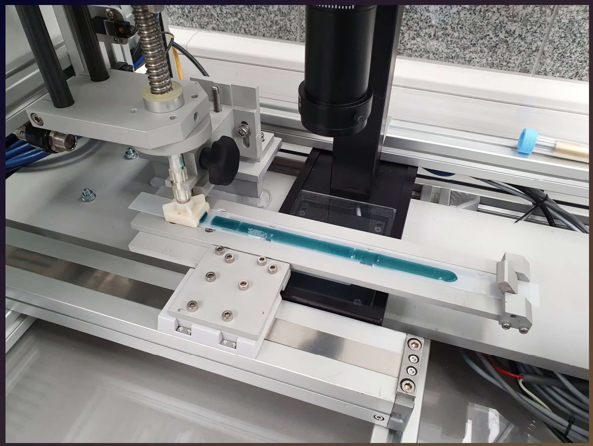

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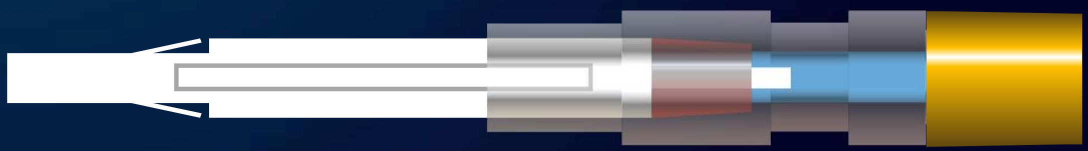

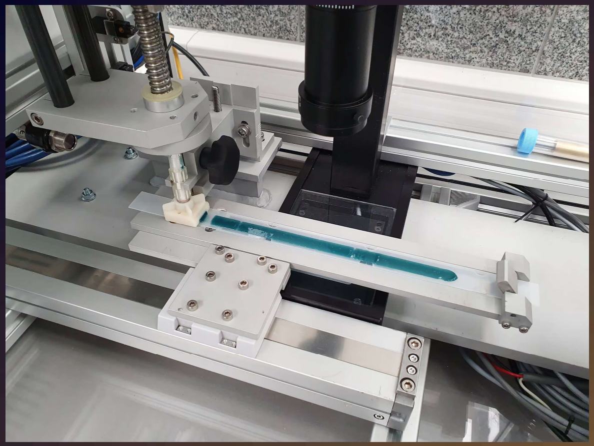

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The Energy Problem

"Energy losses due to friction and wear could potentially be reduced by 40% in the long term (15 years) and 18% in the short term (8 years). On a global scale these savings would amount to 1.4% of the GDP annually and 8.7% of the total energy consumption in the long term"

- Holmberg, Erdemir (2017) Friction

"23% of the world's total energy consumption originates from tribological contacts. Of that 20% (103EJ) is used to overcome friction and 3% (16EJ) is used to remanufacture worn parts and spare equipment due to wear and wear-related failures"

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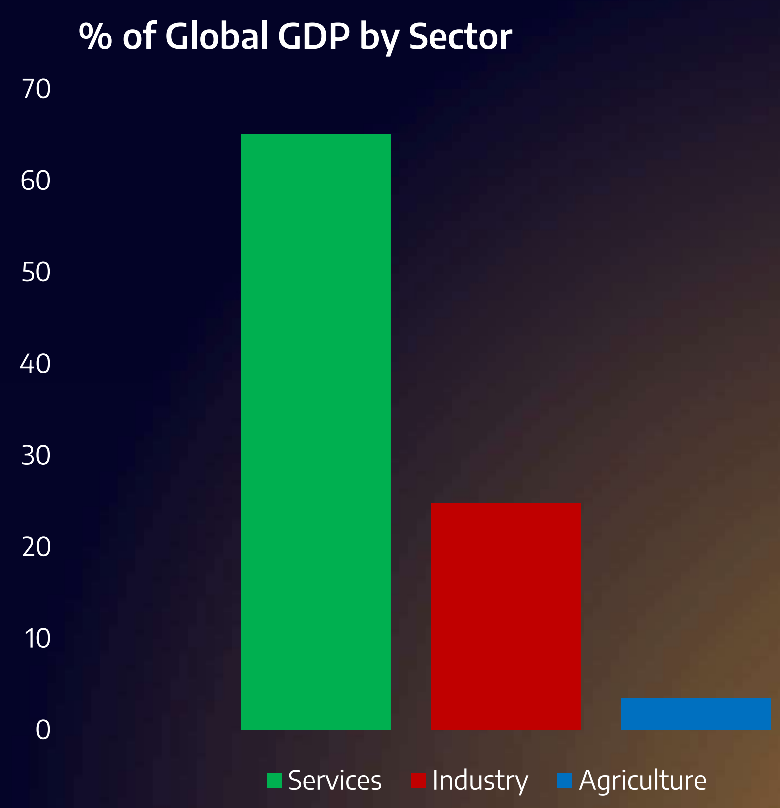

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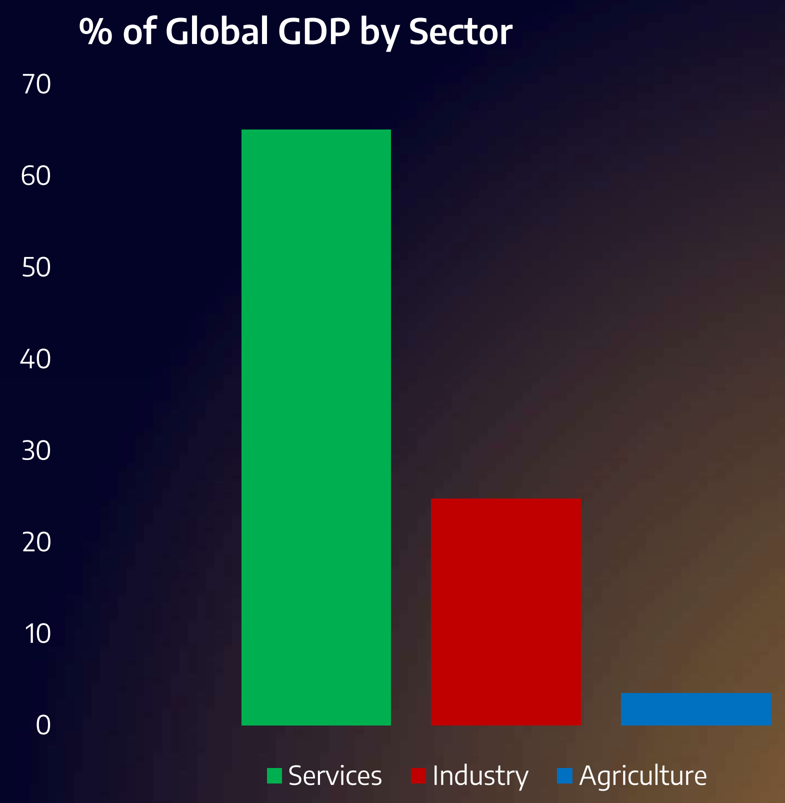

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