Lubrication Fundamentals

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- CITGO Sr. Technical Services Representative
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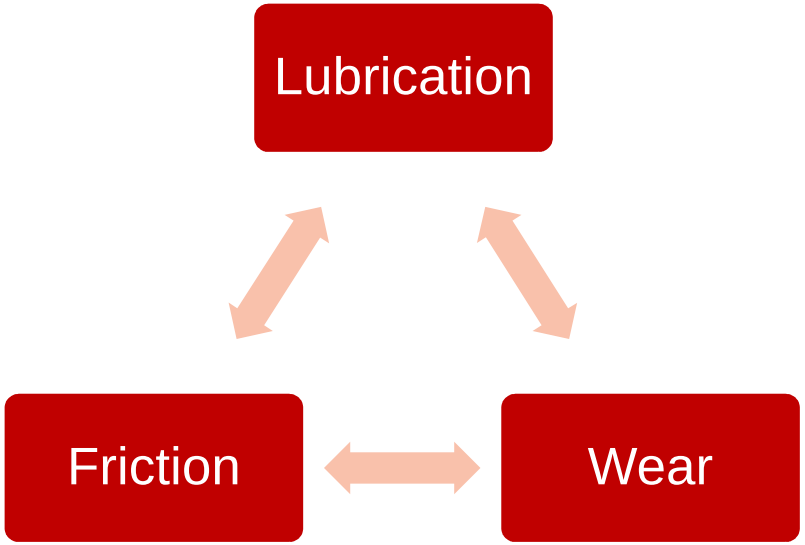
  - Certified Lubrication Specialist
  - Oil Monitoring Analyst I
- NLGI Certified
  - Certified Lubricating Grease Specialist
- Active in STLE, NLGI, and ASTM

Agenda

- What is Tribology?
- Friction
- Lubrication
- Wear

What is Tribology?



Tribology is the science and engineering of interacting surfaces in relative motion.

physics – chemistry – applied mathematics – metallurgy – material science – mechanical engineering – chemical engineering – applied mechanics

A Brief Tribute to Professor H. Peter Jost, CBE

- January 25, 1921 – June 7, 2016
- British mechanical engineer
- Founded the discipline of Tribology
- Jost Report (1966)

Courtesy: Machinery Lubrication

Lubrication

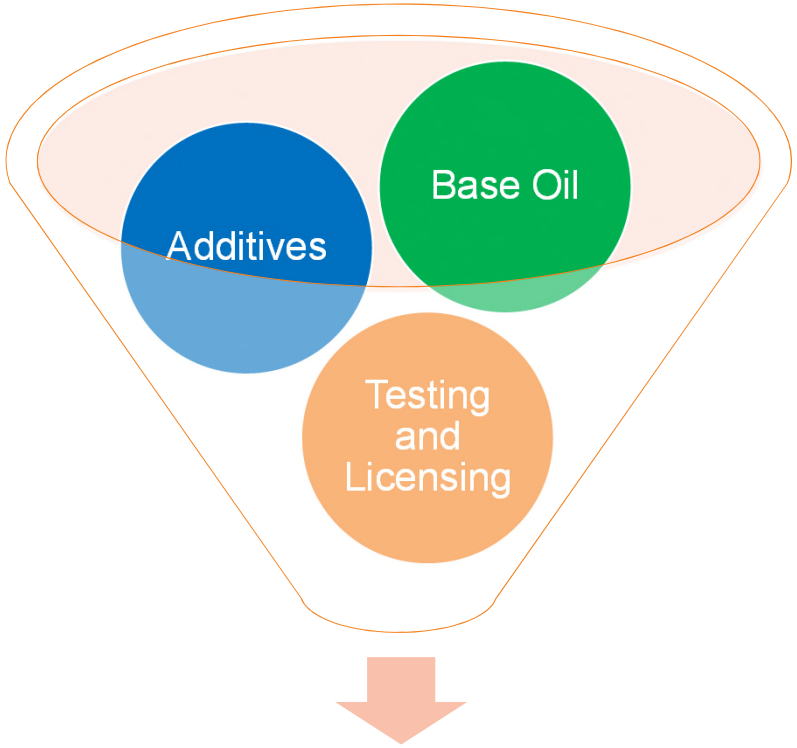
- Lubricant: A substance used to reduce friction between two surfaces in relative motion
- Gas
- Solid
- Liquid

Additional Functions of Lubricants

- Clean
- Seal
- Reduce wear
- Prevent rust and corrosion
- Neutralize acids
- Prevent foaming
- Emulsify water
- Separate water
- Transfer heat
- Remove contaminants
- Liquid dielectric
- Transmit power
- Dampen shock

Equipment Condition → Equipment Performance

Where do Lubricants Come From?



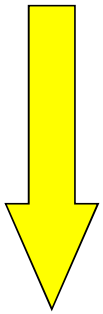
Finished product meeting user, industry, and OEM specifications

Base Stock Types

Petroleum (Mineral)	Synthetic	Vegetable (Bio-based)
• Paraffinic • Naphthenic • Virgin or re-refined	• Synthetic hydrocarbons (ex: PAO) • Esters (ex: diester, polyolester, etc.) • Others (ex: polyglycol, silicone)	• High oleic canola oil • Sunflower seed oil • Palm oil • Rapeseed oil

API Base Oil Groups – General Properties

Increased refining



API Group	Saturates, wt.%		Sulfur, wt.%	Viscosity Index
Group I	<90	And/or	>0.03	80 – 119
Group II	≥90	And	≤0.03	80 – 119
Group III	≥90	And	≤0.03	120 Min
Group IV	All PAOs			
Group V	All base stocks not included in Groups I-IV, including naphthenic			

Base oil interchange guidelines: API 1509, E.1.3

Viscosity

Viscosity: a fluid's resistance to flow

Dynamic (Absolute)

Kinematic

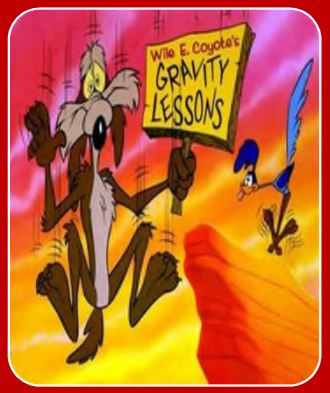
Dependent upon:

Temperature

Pressure

Shear rate

Viscosity Measurement Systems



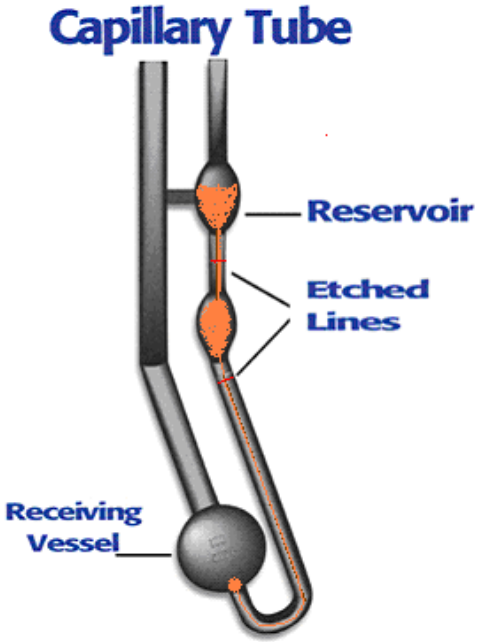
Kinematic (falling)

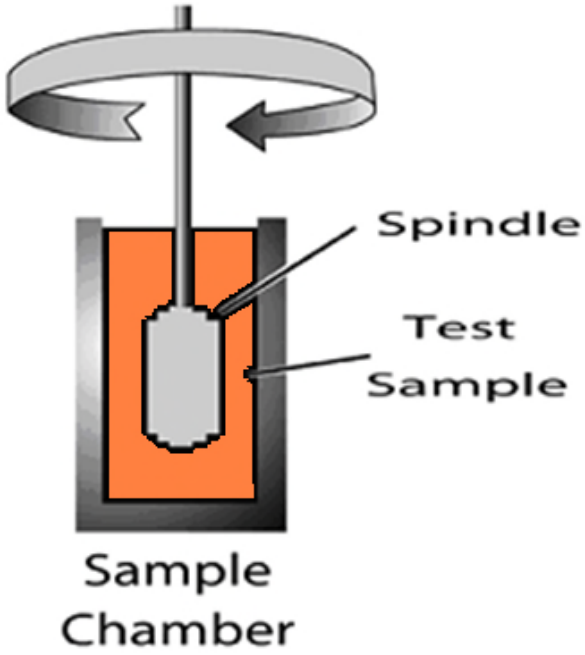
- cSt: centistokes, 40°C and 100°C
- SUS: Saybolt Universal Seconds, 100°F and 200°F
- Basis for ISO classification
- Kinematic viscosity x specific gravity = dynamic viscosity
- SUS / 5 = cSt (approximate)
- Engine oil, hydraulic oil

Dynamic (getting pushed around)

- cP: centipoise
- Internal resistance to flow and shear
- Low-temperature properties (ATF Brookfield, PCMO CCS)
- Shear stress / shear rate = cP

Viscosity Measurement Apparatus

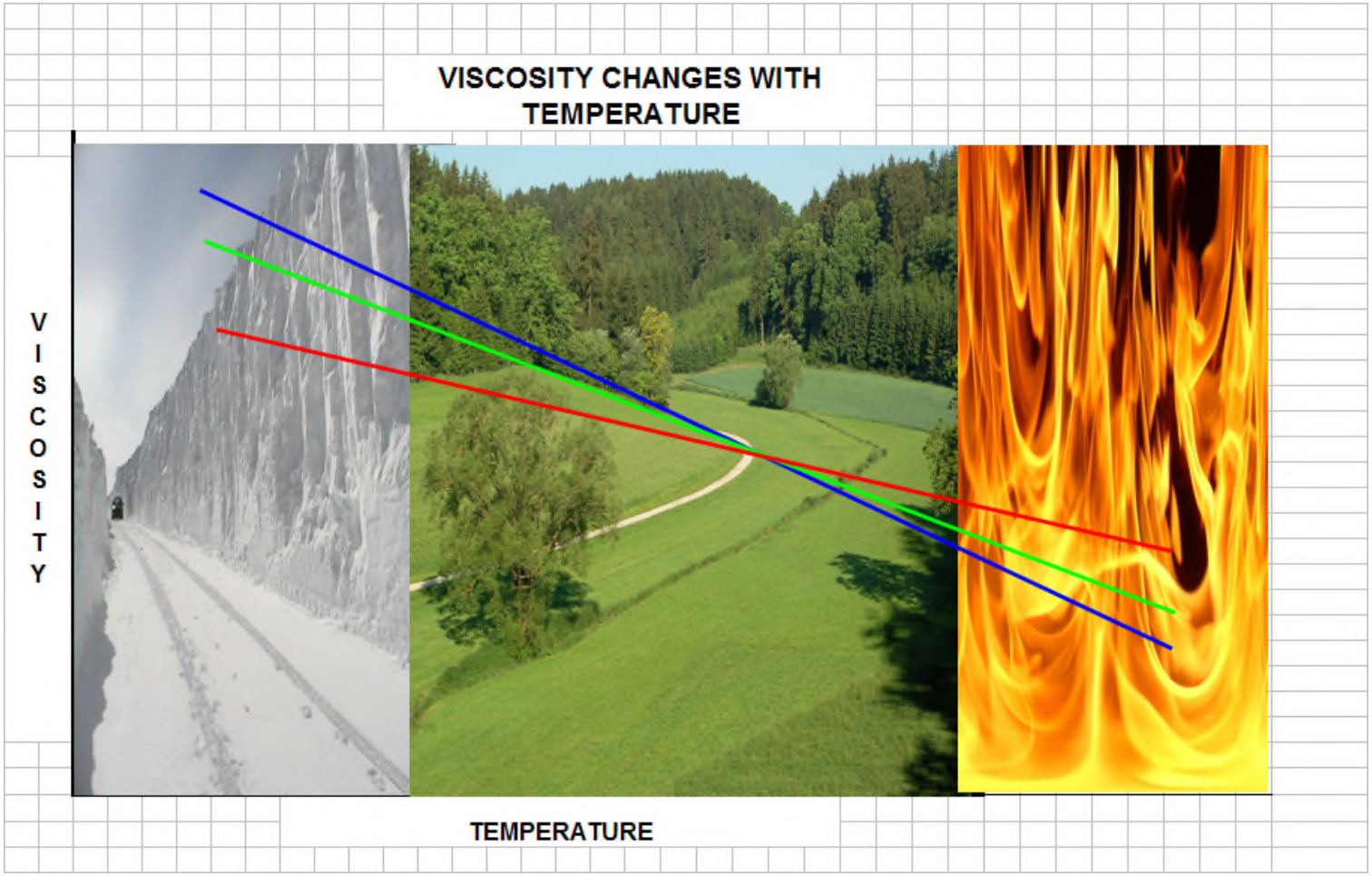




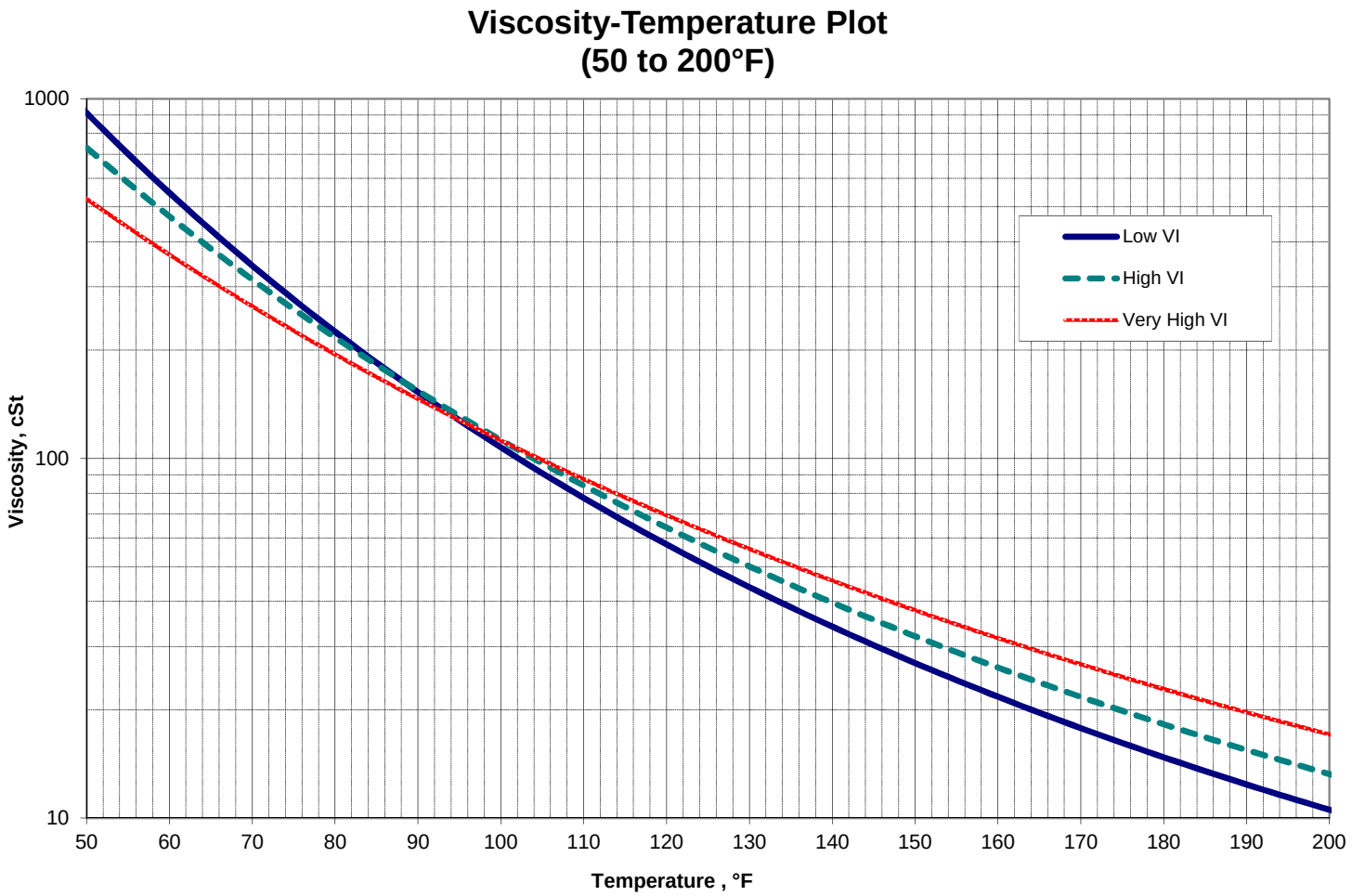
Kinematic (time)

Dynamic (shear)

Viscosity Index



Viscosity Index



Viscosity Depends on Temperature, Pressure, and Shear Rate

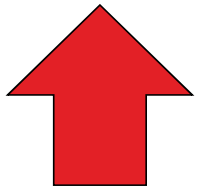
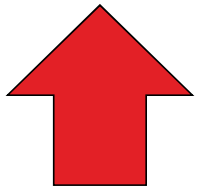
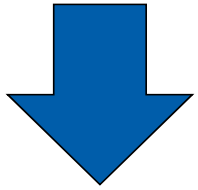
The following three oils all have the same viscosity at 100°C (SAE 30)
They have different viscosities at 40°C.
How do you differentiate these oils?

	Viscosity 100° C cSt	Viscosity 40° C cSt	Viscosity 150° C cSt	VI	Pressure Viscosity coefficient α	Viscosity @ 1GPa and 100° C
A	10	65	4.2	135	1.4	40.5
B	10	85	3.8	97	1.8	60.5
C	10	105	3.6	66	2.8	165.5

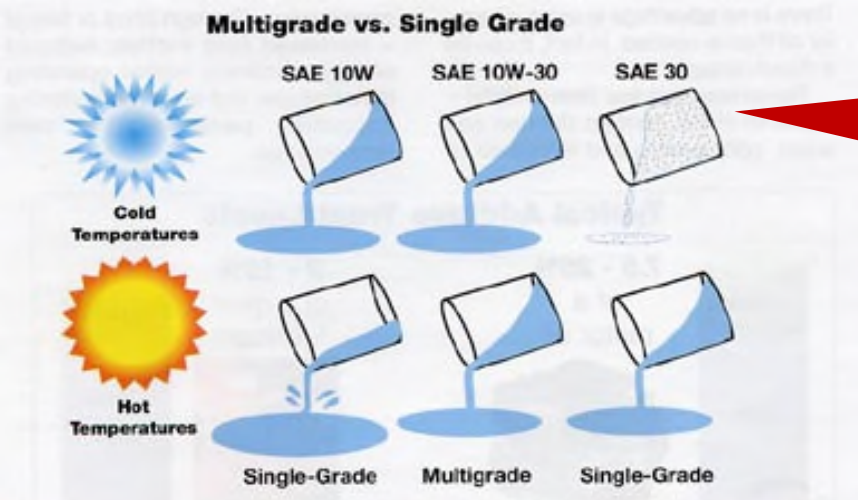
VI = Viscosity Index

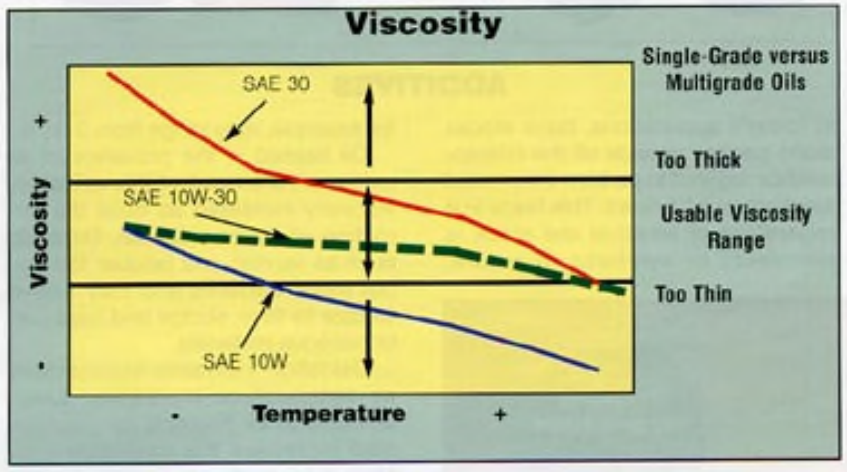
"Resistance to viscosity change with temperature"
related to empirical 1920's 0-100 scale

Viscosity Selection

Operational Condition	Viscosity Needed
Higher load	
Higher temperature	
Higher speed	

Cold Temperature Start-up

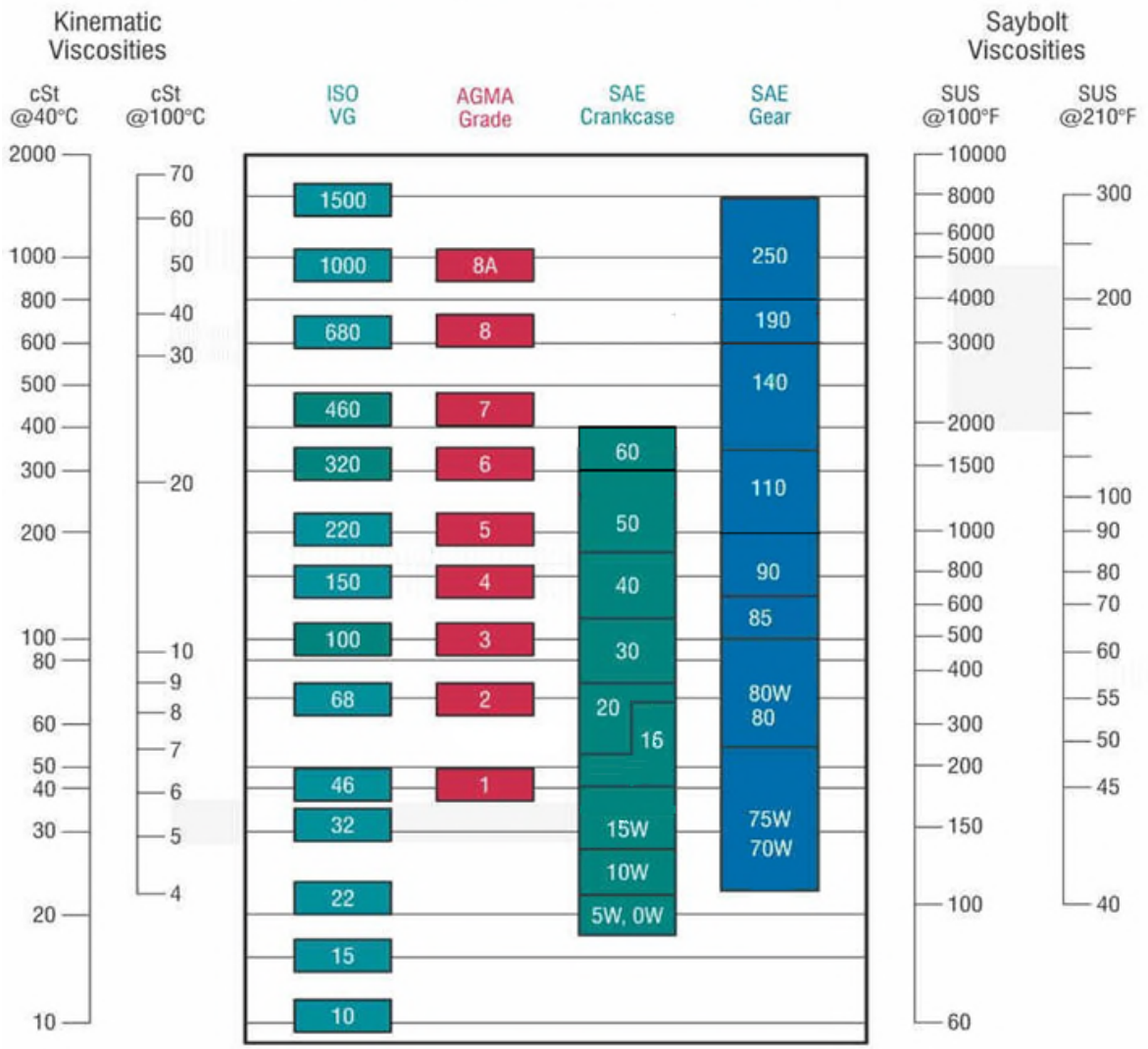




How do you pump this to critical areas soon after startup?

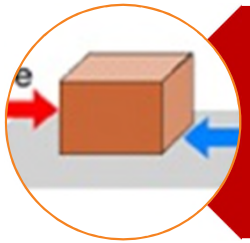
Automotive Lubricant Viscosity Grades Engine Oils – SAE J300 SEPT 2015					
SAE	Low Temperature Viscosities		High-Temperature Viscosities		
Viscosity Grade	Cranking (mPa.s) max at temp °C	Pumping (mPa.s) max at temp °C	Kinematic (mm^2/s) at 100°C		High Shear Rate (mPa.s) at 150°C, 10/s
			min	max	min
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	13 000 at -10	60 000 at -15	9.3	—	—
8			4.0	<6.1	1.7
12			5.0	<7.1	2.0
16	---	---	6.1	<8.2	2.3
20	—	—	6.9	<9.3	2.6
30	—	—	9.3	<12.5	2.9
40	—	—	12.5	<16.3	3.5
40	—	—	12.5	<16.3	3.7
50	—	—	16.3	<21.9	3.7
60	—	—	21.9	<26.1	3.7

Table 2. Comparative Viscosity Classifications

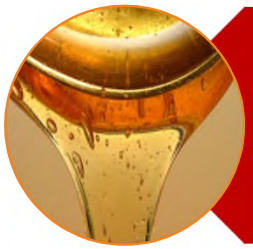


Friction

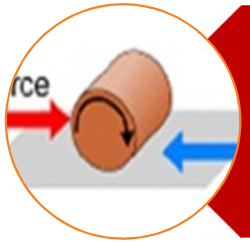
Friction: the resistance that one surface or object encounters when moving over another



Dry/solid friction



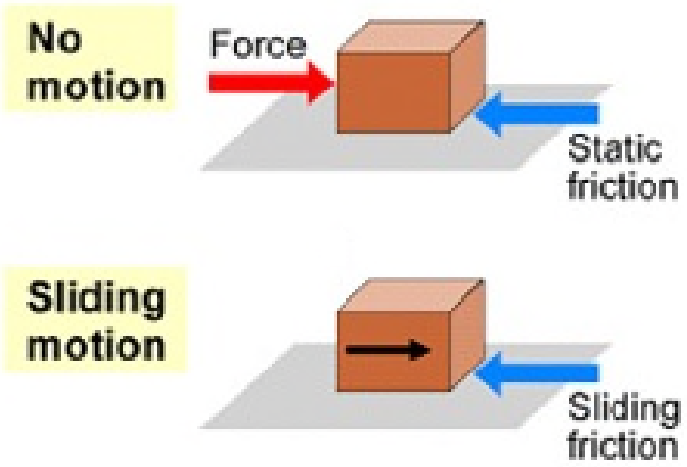
Fluid friction



Rolling friction

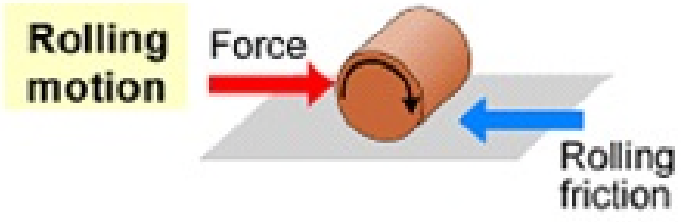
Stick-slip friction

Coefficient of friction, μ = $\frac{\text{force to move surface horizontally}}{\text{pressure between the surfaces}}$

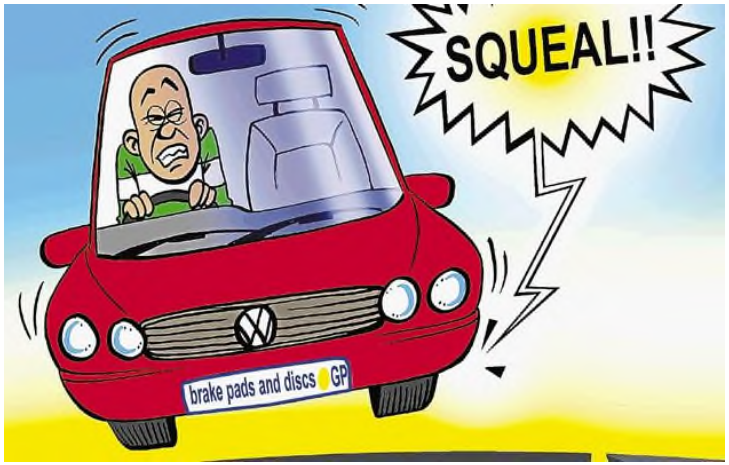


Dry/solid friction

Fluid friction



Rolling friction



Stick-slip friction

Many Ways to Measure Friction

wear scar – angle – load

Ball on three discs
(BOTD)

Scuffing Load Ball on Cylinder Lubricity Evaluator
(SLBOCLE)
ASTM D6078

High Frequency Reciprocating Rig
(HFRR)
ASTM D6079

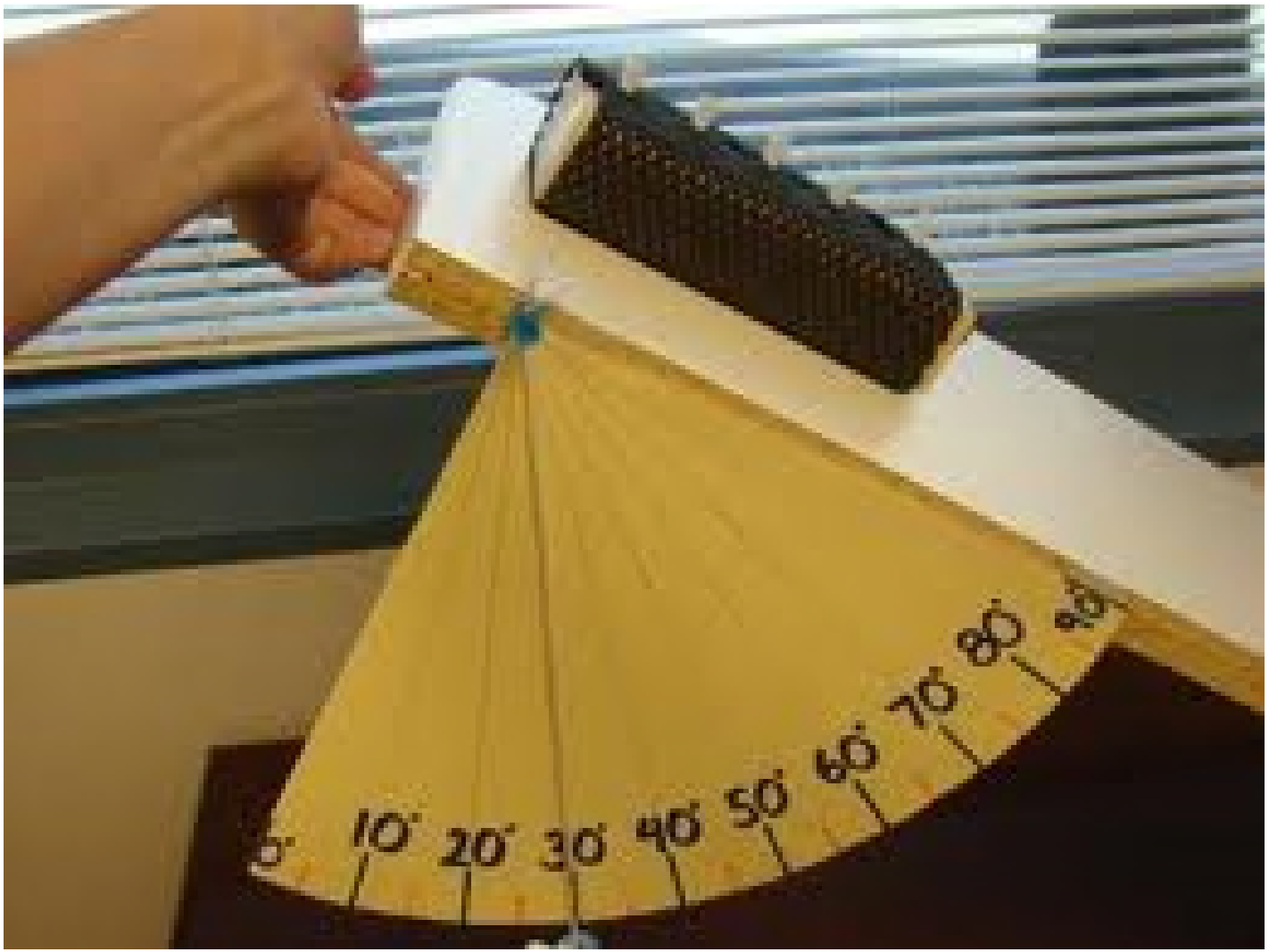
Ball on Cylinder Lubricity Evaluator
(BOCLE)

Mini Traction Machine
(MTM)

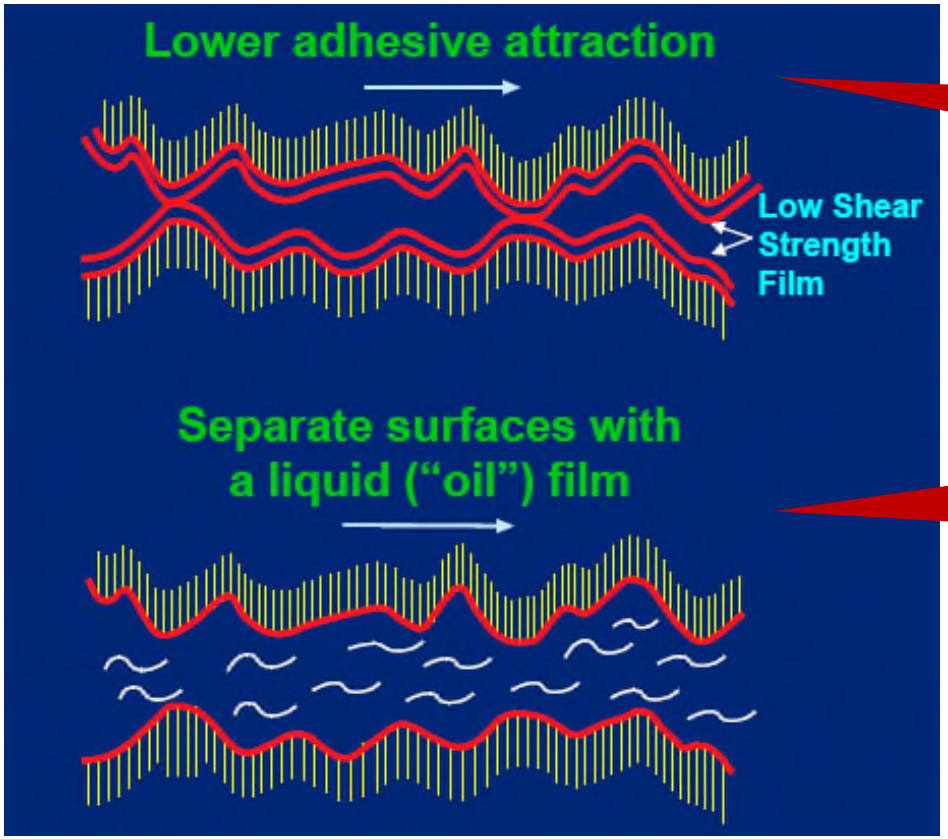
Clark Sliding Ramp
(CSR)

Calculate/measure a coefficient of friction
(μ)

Clark Sliding Ramp



Ways to Reduce Friction With Lubricants



Minimize mechanical friction

Eliminate mechanical friction; substitute fluid friction

Three Major Lubrication Regimes

Boundary lubrication

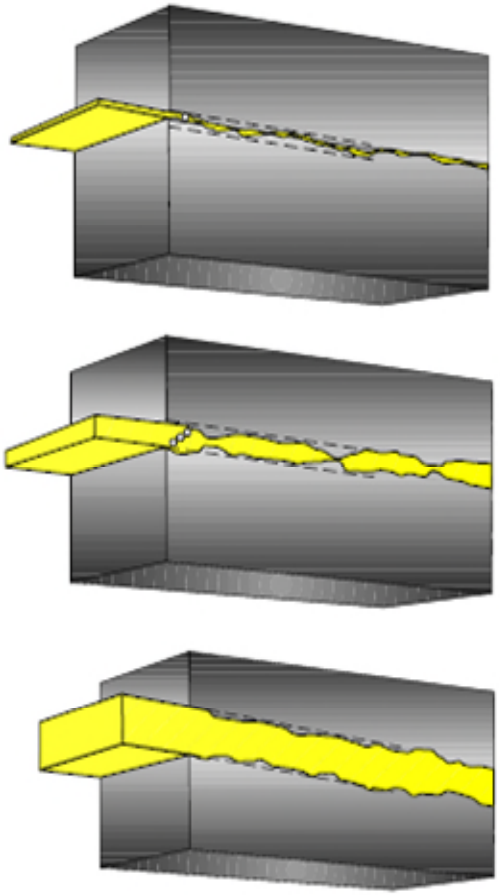
Separation by molecules attached to the surfaces

Mixed lubrication

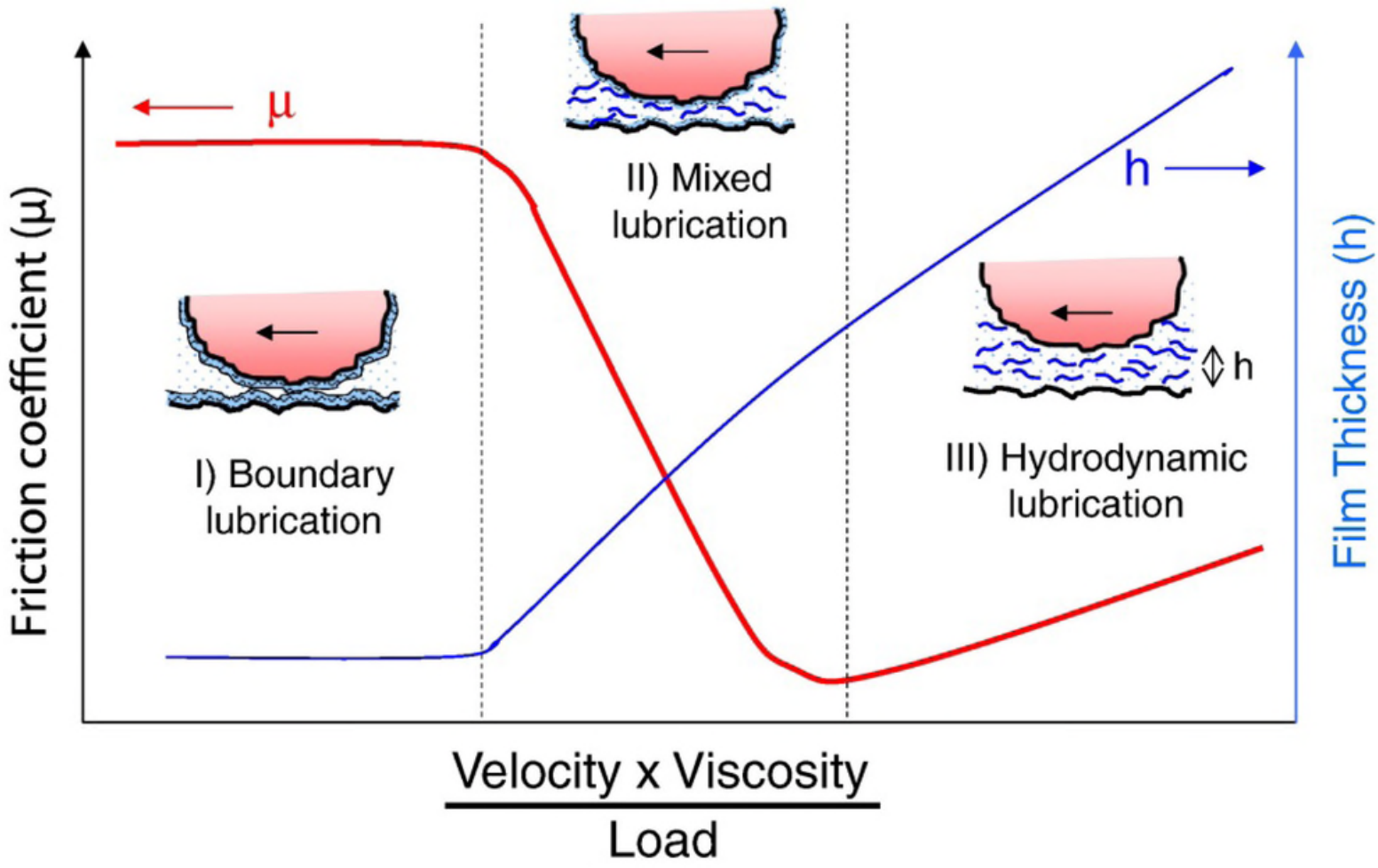
Incomplete separation

Hydrodynamic lubrication (full film)

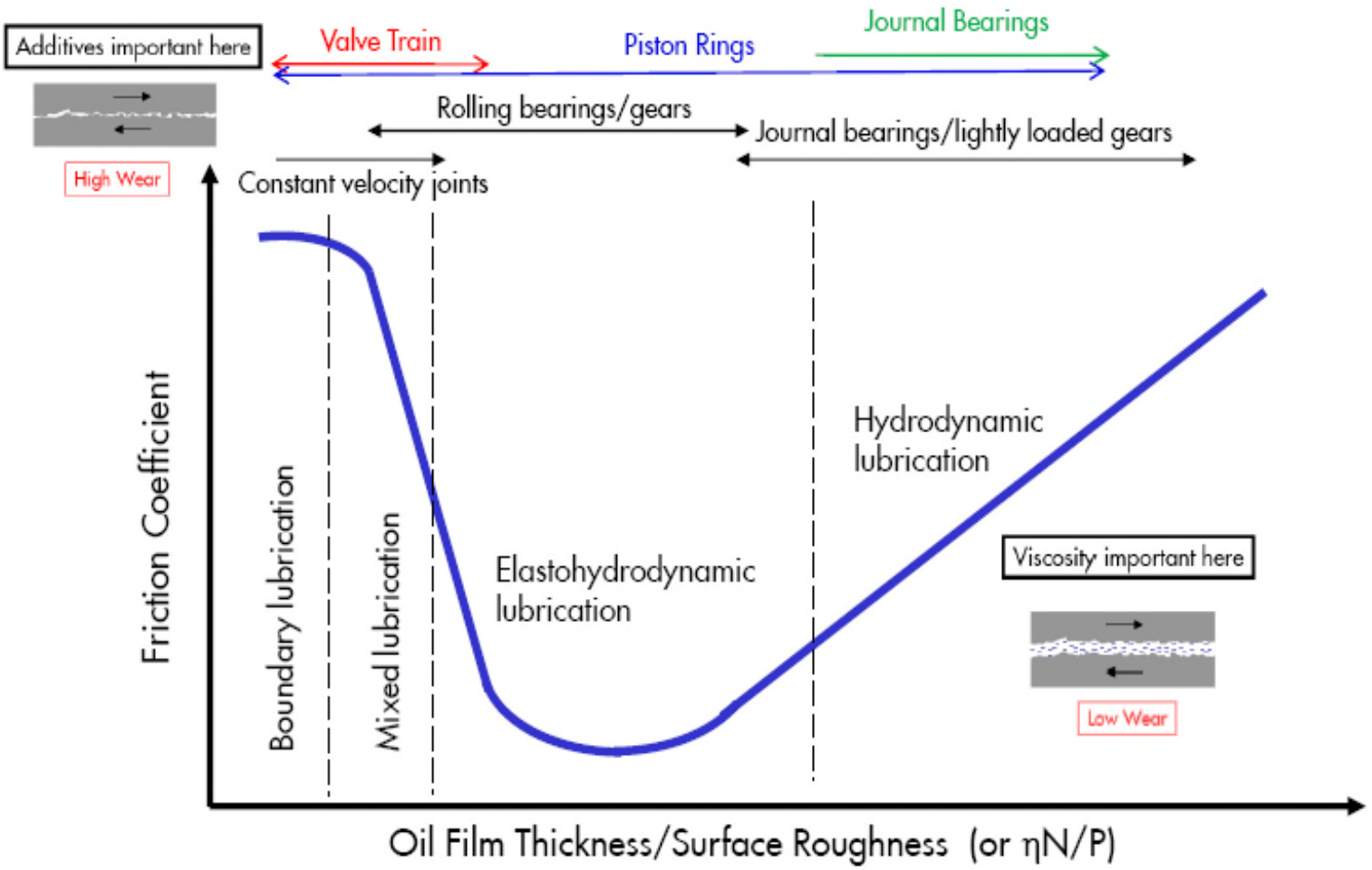
Complete separation, 3 modes



Lubrication Regimes – Stribeck Curve



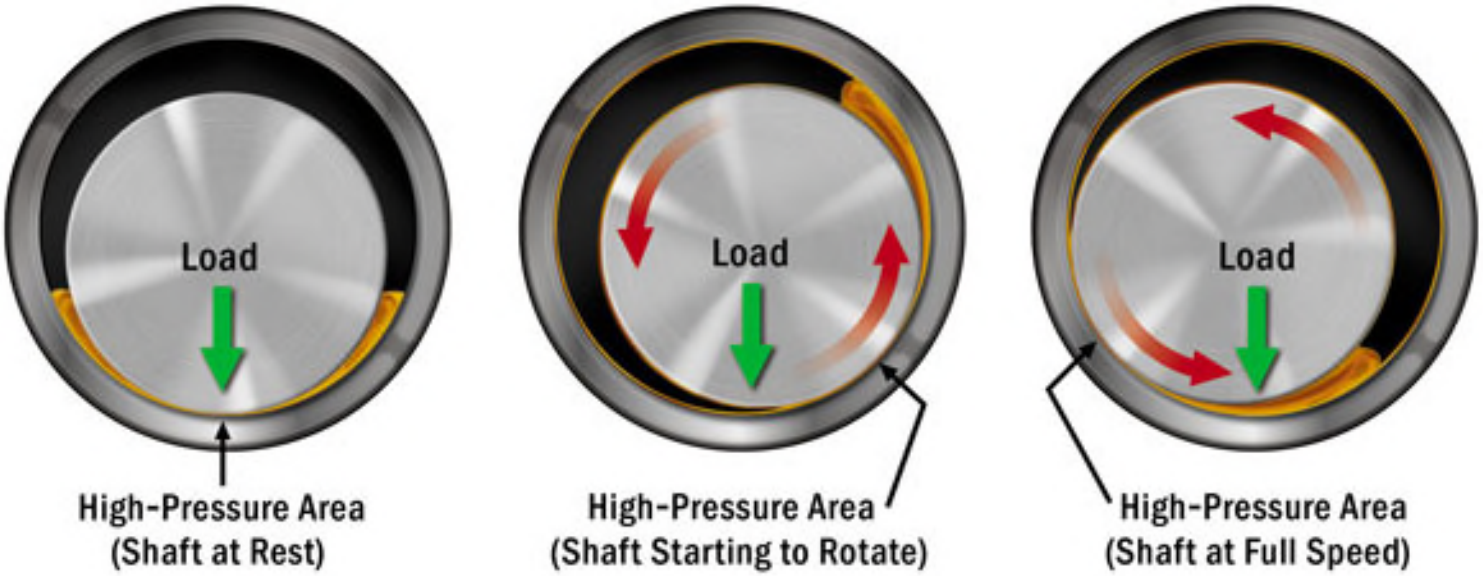
Several Regimes Can Occur at Once



Lubrication Regime Key Factors

Hydrodynamic and Elastohydrodynamic	Boundary and Mixed
• Temperature • Pressure • Shear rate • Film thickness	• Friction modifiers • Anti-wear • Extreme pressure (EP)

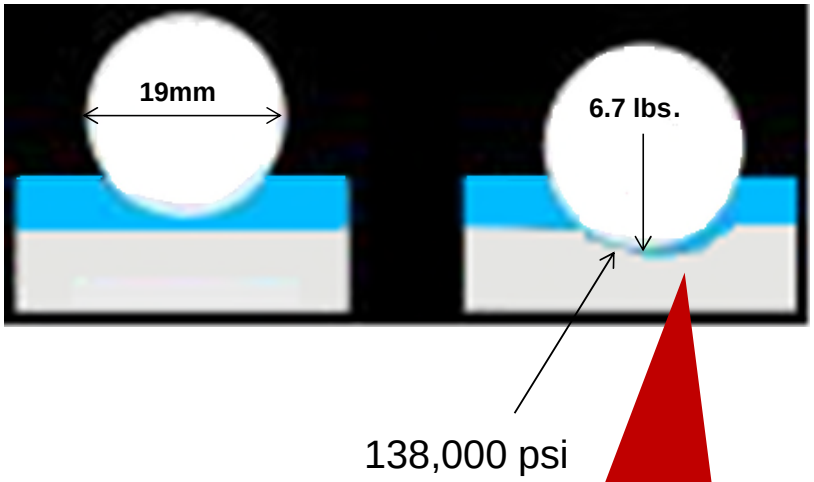
Hydrodynamic Film in a Bearing



- What happens to the **film thickness** if we increase the **viscosity**?
- What happens to the **coefficient of friction** if we increase the **viscosity**?
- What happens to the **film thickness** if we increase the **load**?
- What happens to the **film thickness** if we increase the **speed**?
- What happens to the **coefficient of friction** if we decrease the **load**?

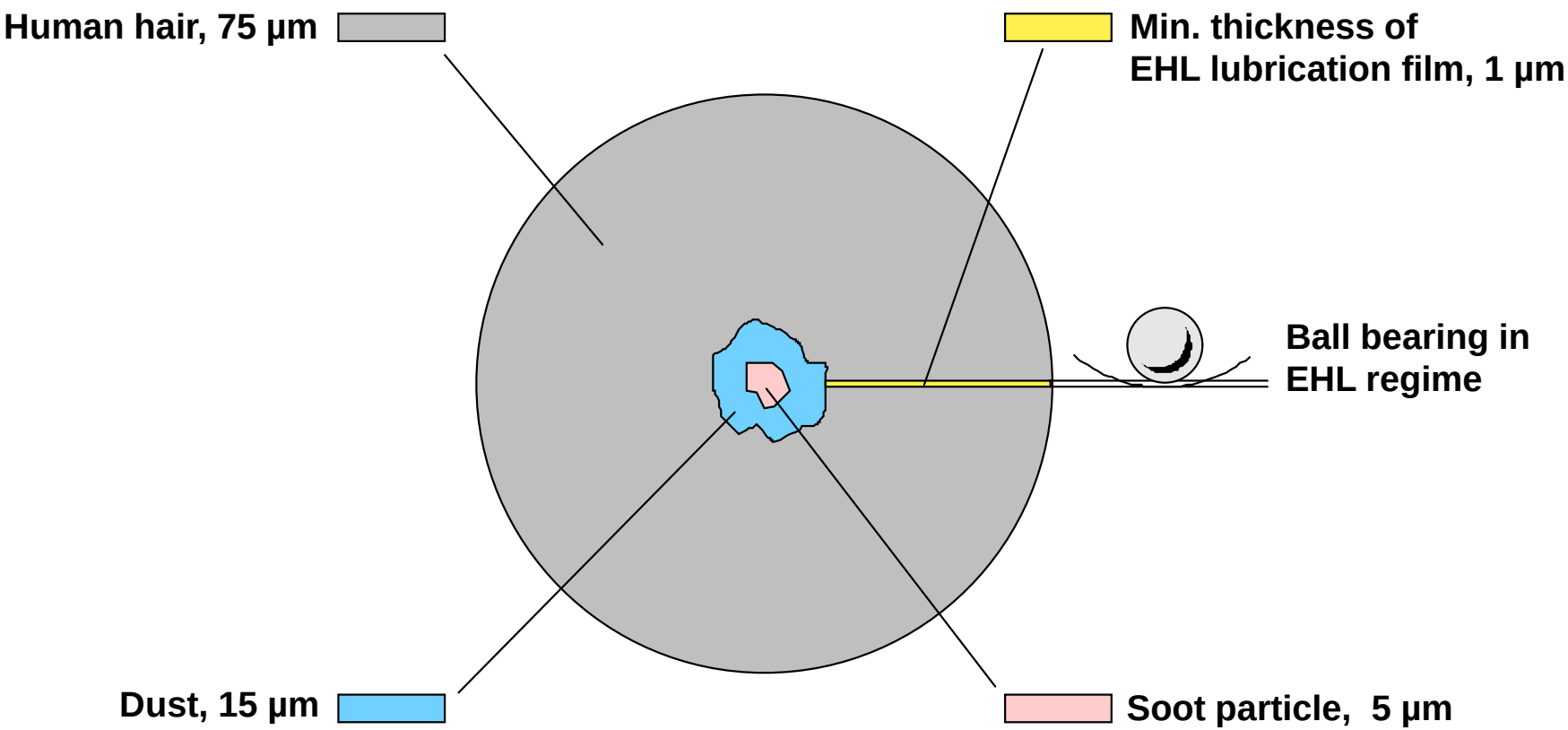
Hydrodynamic (full film) Journal Bearings

Elastohydrodynamic Lubrication: Ball Bearings

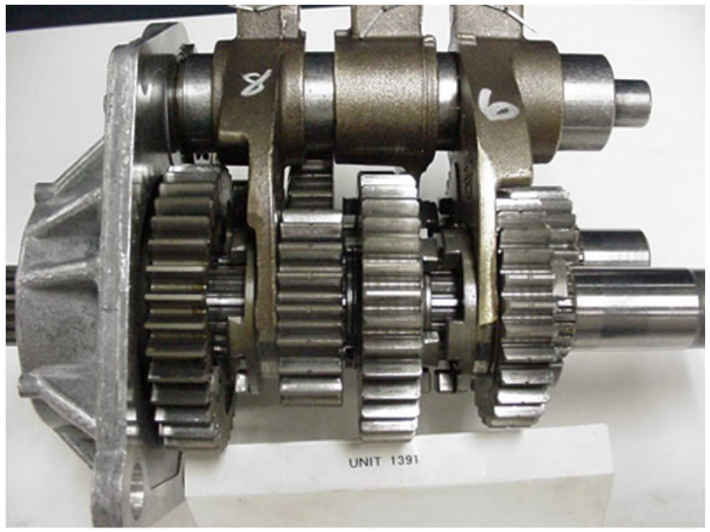


Contact zone effects:
- **Deformation of surfaces**
- **Fluid becomes semi-solid**

Relative Sizes



Boundary Lubrication: High Loads



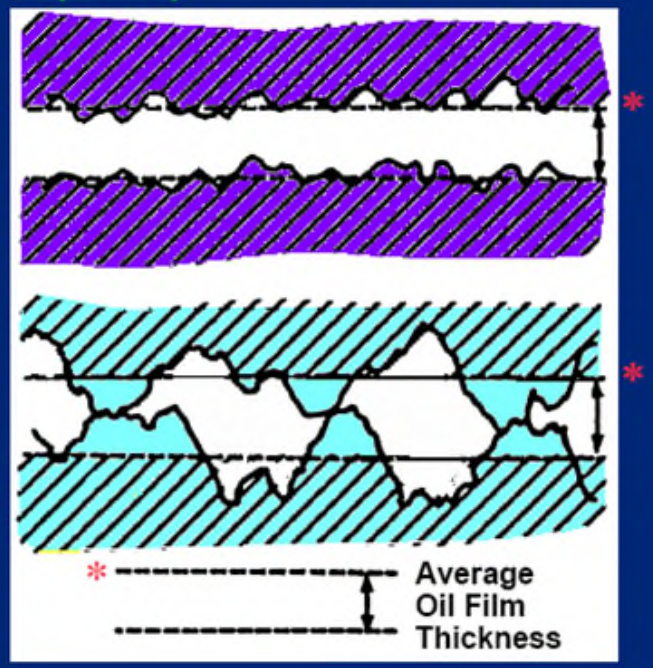
Viscosity and Film Thickness

$$\text{Film Thickness} \propto \frac{(\text{Viscosity} \times \text{Speed})^x}{(\text{Load})^y}$$

- Film thickness must be 3x surface roughness to prevent metal/metal contact (boundary lubrication)

λ

- Higher viscosity lubricants yield thicker films



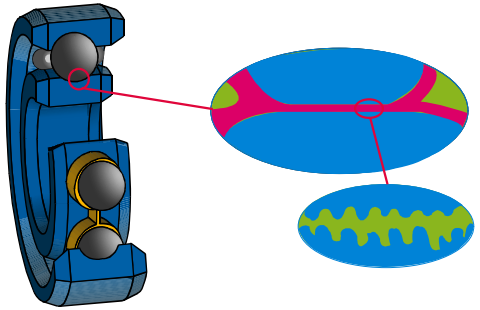
Lambda (Λ) Ratio

The Lambda Ratio is defined as follows:

$$\Lambda = h_0/\sigma$$

Where h_0 = Lubricant Film Thickness

σ = Average Surface Roughness

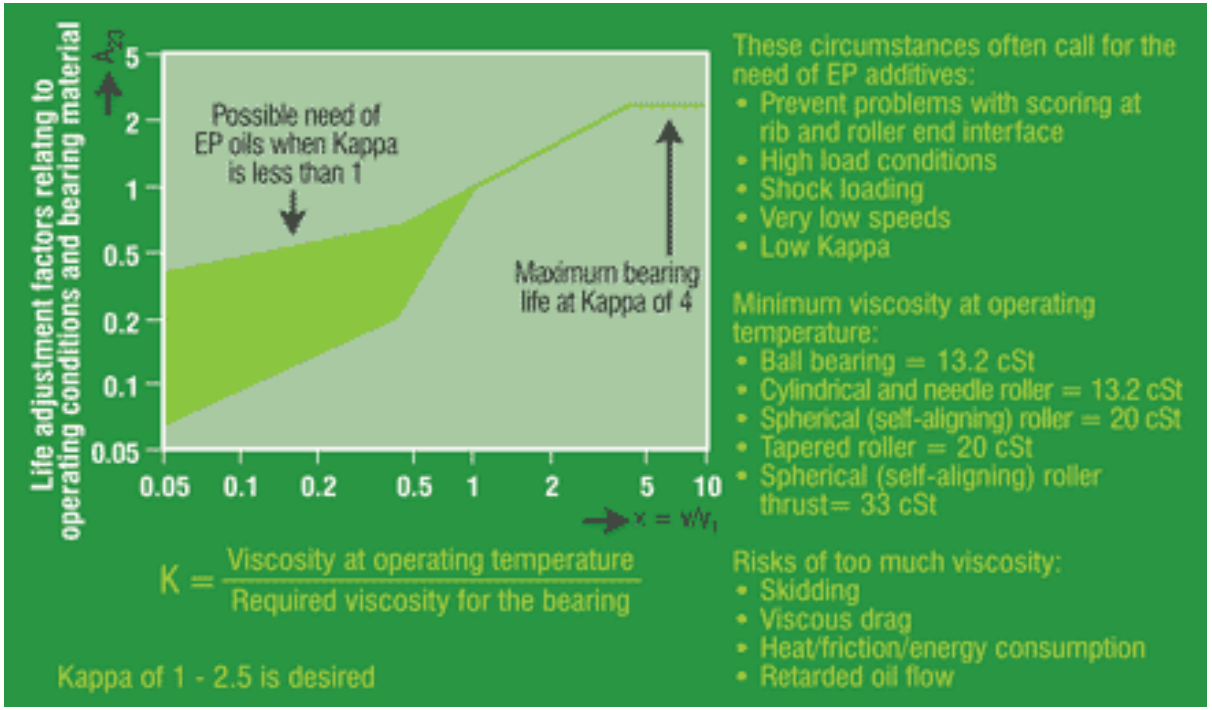


Λ Ratio	Lubrication Regime	Wear Observation
<1.0	Boundary	Surface smearing or deformation
1.0 – 1.5	Mixed	Surface distress and surface pitting
1.5 – 3.0	Mixed	Surface glazing with subsurface fatigue
>3.0	EHL	Minimal wear, long life, eventual subsurface fatigue failure

Kappa (K) Value

Kappa is the ratio of the viscosity of the lubricant at operating temperature divided by the required viscosity for the bearing

Kappa	Lubrication Conditions
<0.4	Mixed friction, increased solid contact
1	The basic rating life of the bearing is achieved
4	Full fluid film lubrication
>4	Full fluid film lubrication, possible temperature rise due to fluid friction



Graphic from Machinery Lubrication

Bearing Speed Factor

Speed Factor = $n \bullet D_m$

Where n = bearing operating speed, rpm

D_m = mean bearing diameter, mm

$D_m = (ID + OD)/2$

ID = Inside Diameter, mm

OD = Outside Diameter, mm

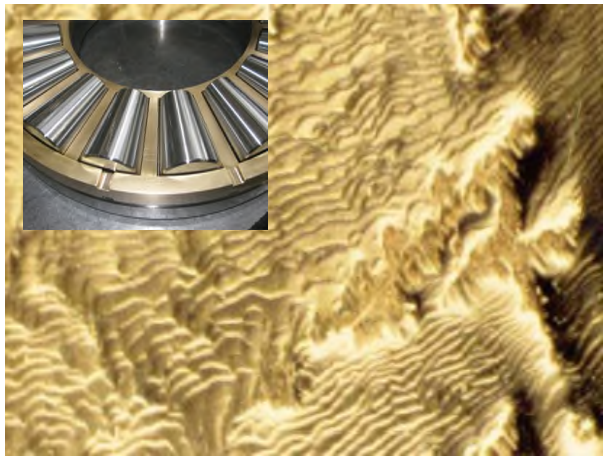
Bearing Type	Oil Lubricated	Grease Lubricated
Radial Ball	500,000	340,000
Cylindrical Roller	500,000	300,000
Spherical Roller	290,000	145,000
Thrust, Ball and Roller	280,000	140,000

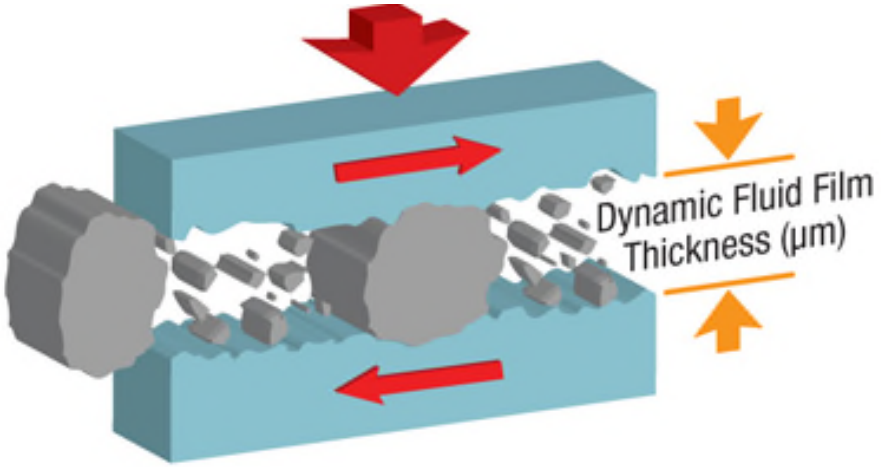
Wear

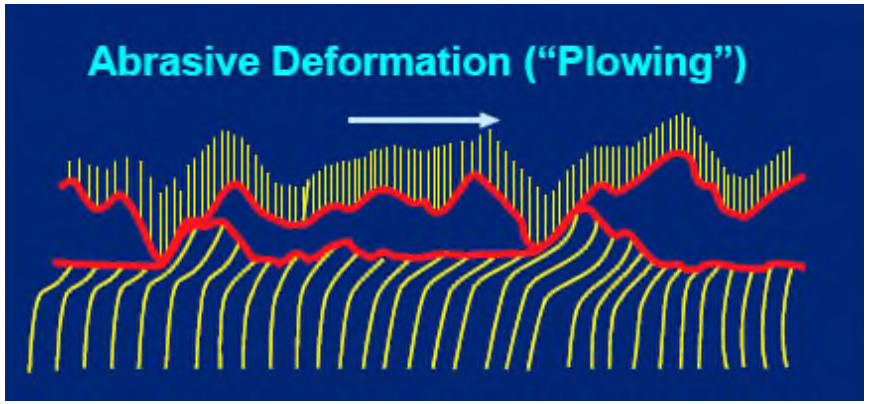
Wear: the rubbing away of surfaces due to mechanical action

- **Abrasive**
- **Fatigue**
- **Adhesive**
- **Erosive**
- **Corrosive**
- **Cavitation**

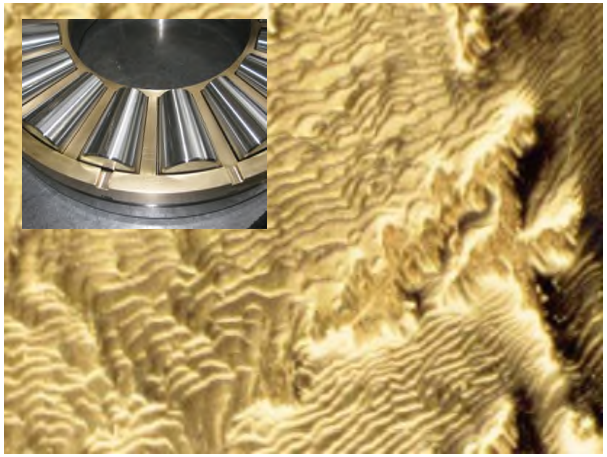
Abrasive Wear

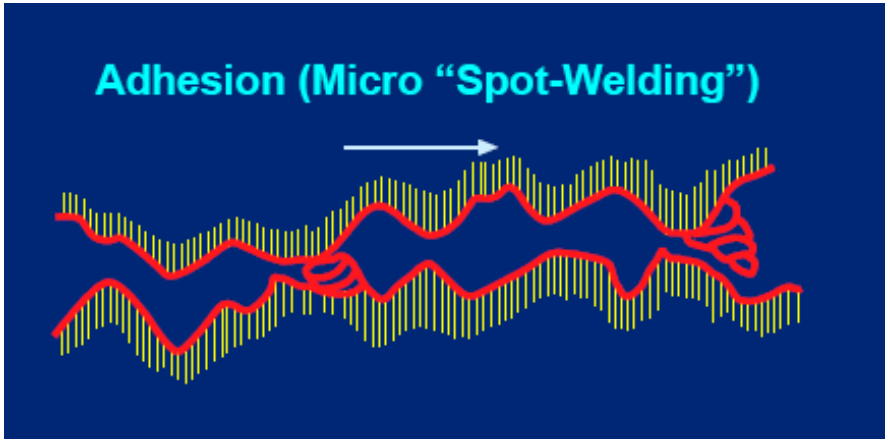






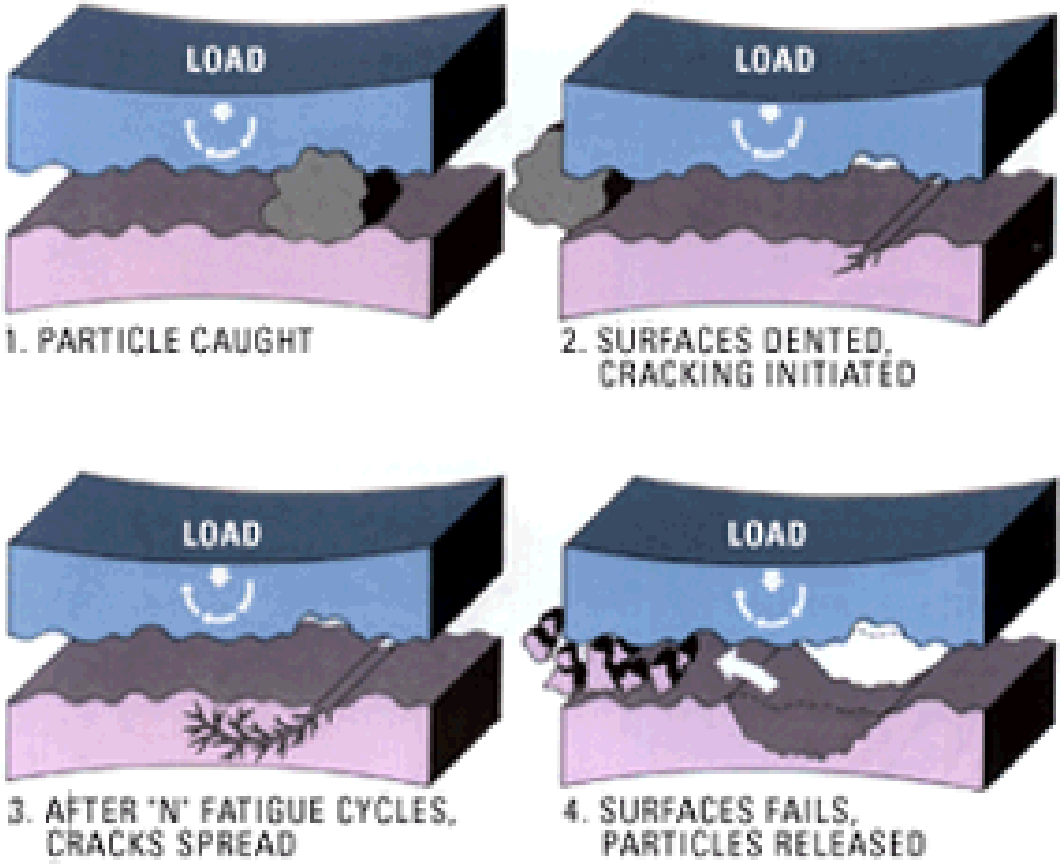
Adhesive Wear





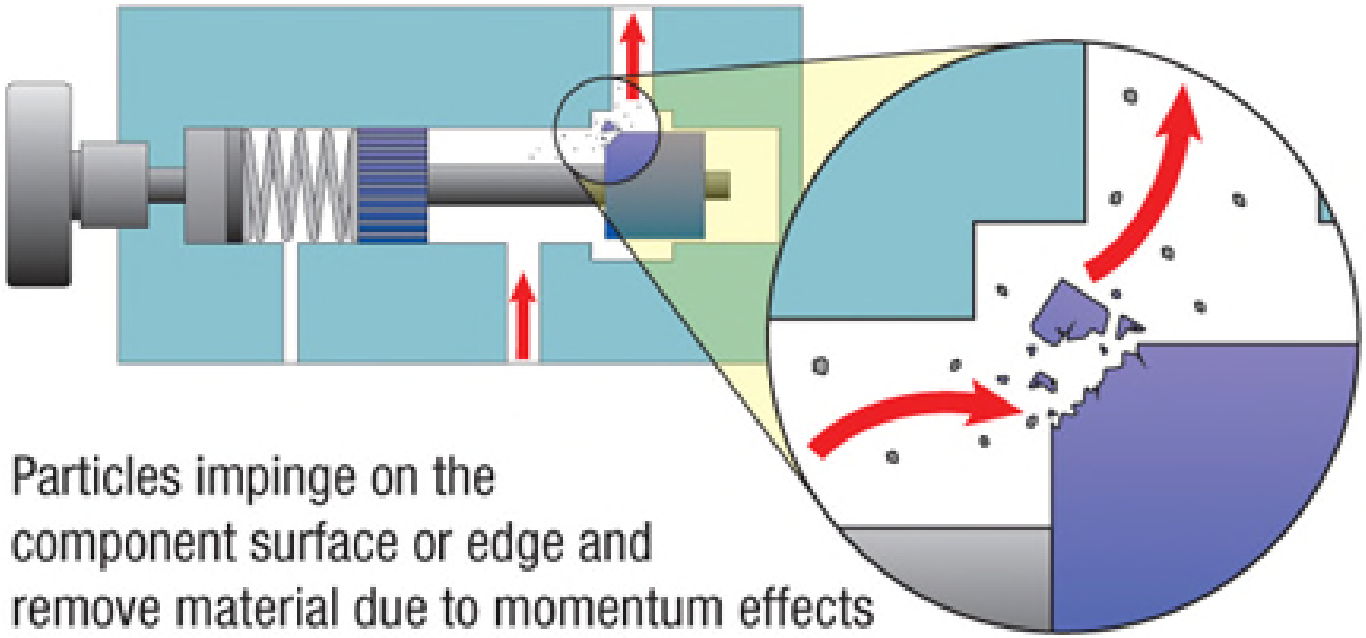
scuffing – scoring – galling

Fatigue Wear



fretting – micro-pitting – spalling

Erosive Wear

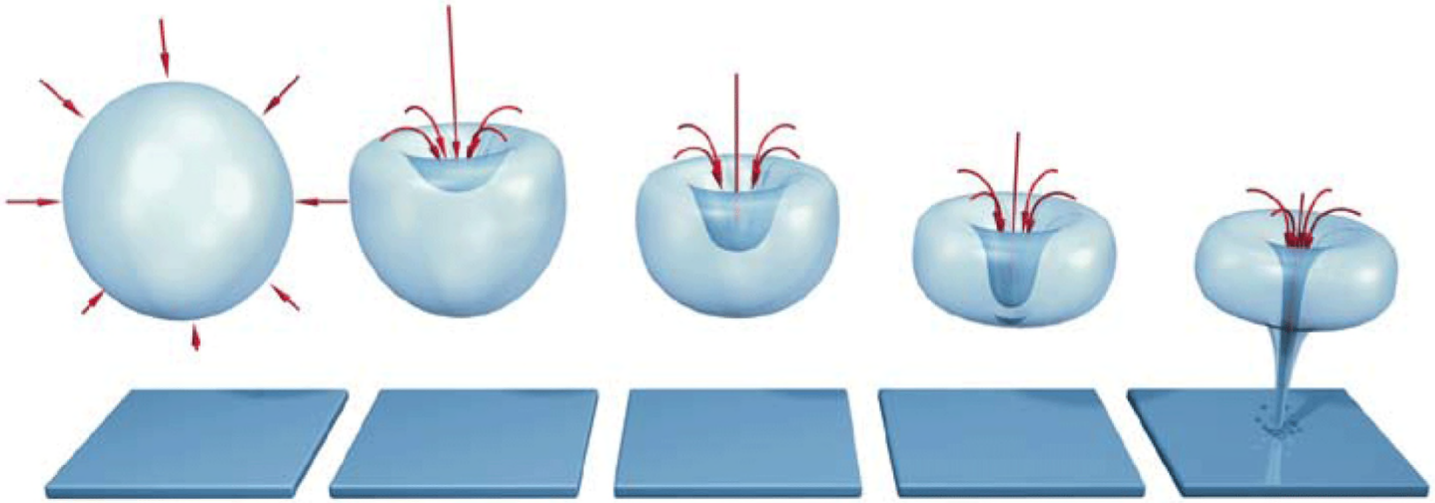


Particles impinge on the component surface or edge and remove material due to momentum effects

Corrosive Wear

Corrosion debris and irregularities lead to abrasive and adhesive wear!

Cavitation Wear



Jet pressure can reach
2,000,000 psi

Questions

- Please post your questions using the Q&A function.

How to Contact Us

- Lubes Answer Line
- **800-248-4684**
  - 8:00 AM - 12:00 PM, 1:00 PM – 5:00 PM CT (Mon – Thurs)
  - 8:00 AM - 12:00 PM, 1:00 PM – 4:30 PM CT (Fri)
- **lubeshelp@citgo.com**
  - Available 24/7

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September 16, 2022	Transmission and Drive Train Lubricants
October 7, 2022	CITGO Metalworking Fluids
October 21, 2022	Clarion Lubricants
November 11, 2022	CITGO Stationary Gas Engine Oils
December 2, 2022	Wireline Lubricants
December 16, 2022	Industrial Gears and Gear Lubrication