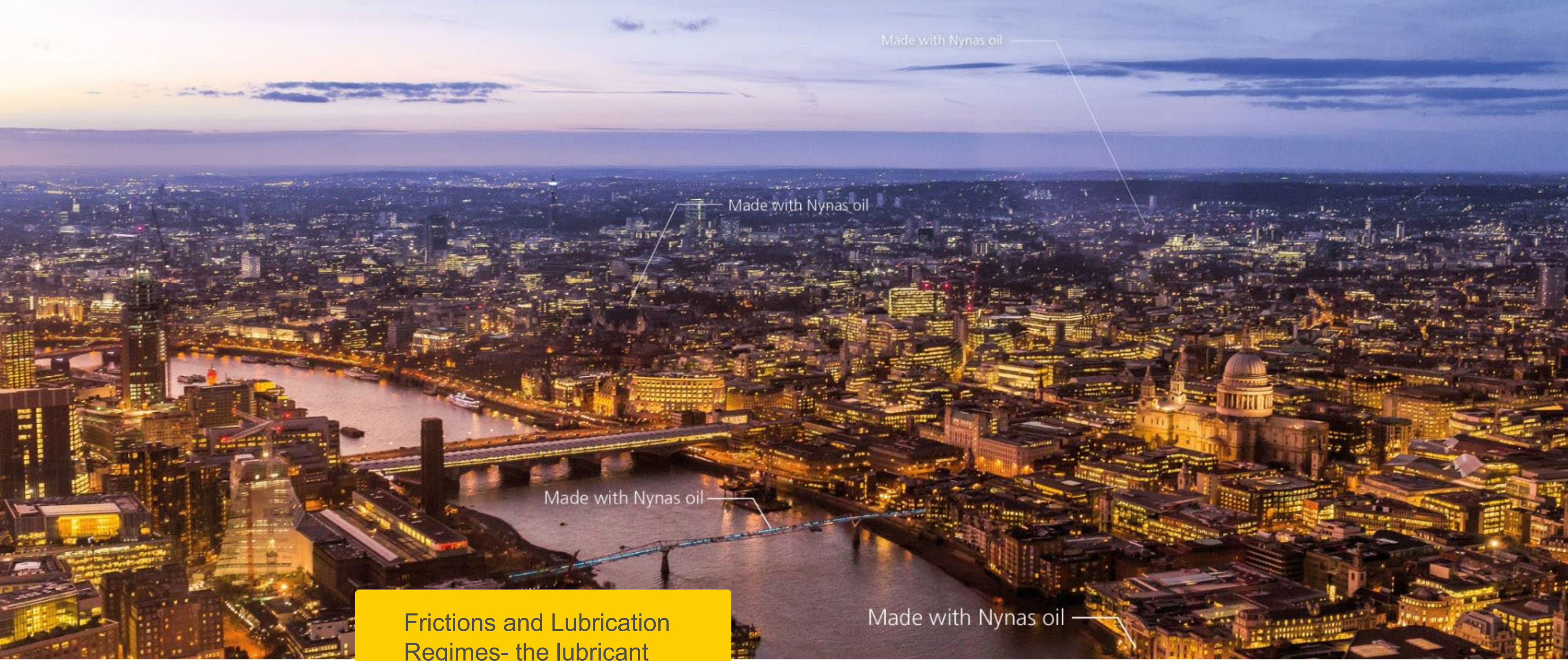


Frictions and Lubrication Regimes- the lubricant designers thinking tools

Thomas Norrby
Adj. Prof. KTH MMK
Technical Manager LUBs
Nynas AB
November 2022

NYNAS

Aerial view of the Nynashamn refinery

- Sweden's first refinery
- Established in 1928
- Massive rock caverns under the tank farm (Atlas Copco probably was involved…)
- Serves the Nordic and global markets

A very different product mix from the one of fuels refiners

NYNAS	FUELS REFINERS
Bitumen for roads and industry	Fuels
Transformer fluids	LPG (Liquefied Petroleum Gas)
Base oils for lubrication and other uses	
Process oils for tires, rubber, adhesives and much more	
Also, some fuel streams sold to other producers for upgrading	Also, minor streams with bitumen, base oils and other

Nynas AB

A brief introduction

Strong health and safety focus and committed to sustainability

Nynas in top 5% for sustainability performances, holding EcoVadis Gold 2022

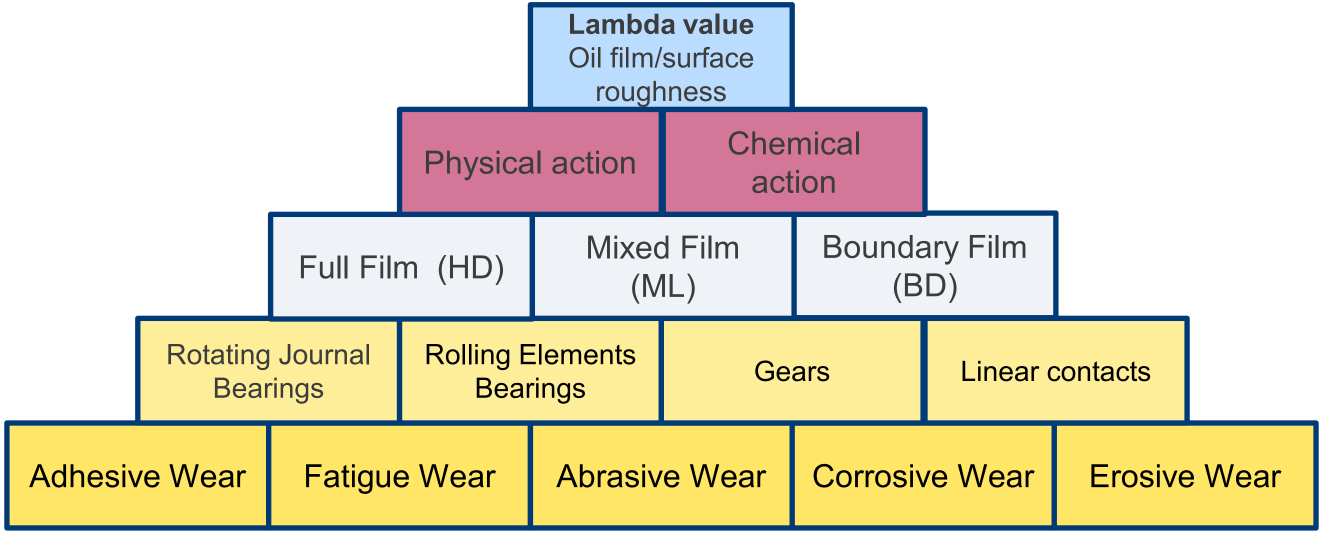
From a small national oil company to an international leader in specialist segments

- 1928 – Nynas builds the refinery in Nynäshamn
- 1950s – the economy recovers, and Nynas petrol station network grows
- 1960s – Nynas bitumen business grows with the Swedish road network expansion
- 1970s – energy crisis makes oil prices skyrocket and crude supplies unreliable
- 1980s – Nynas sells all petrol stations and focuses on specialty products
- 1990s – investment in hydrotreatment technology pays off and the export of specialty oils increases
- 2010s – acquisition of the Harburg refinery
- 2020s – Long-term financing in place and increased focus on solutions for the transition to a sustainable society
- 2028 – Nynas celebrates 100 years! Are you along for the ride?

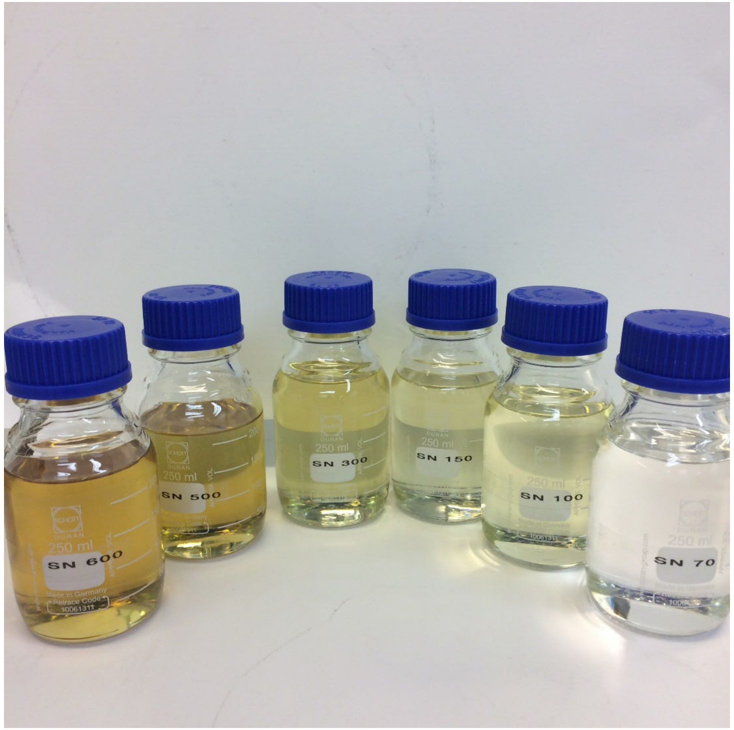
Sustainability runs throughout our value chain – from how we use hydrocarbons in the most sustainable way to make our products, through an efficient supply chain, logistics and product usage.

Base Oils, Additives and Lubricants

The “Frelin Maya Pyramid” - the Building Blocks of Modern Lubrication Technology



Base Oils – for making things!

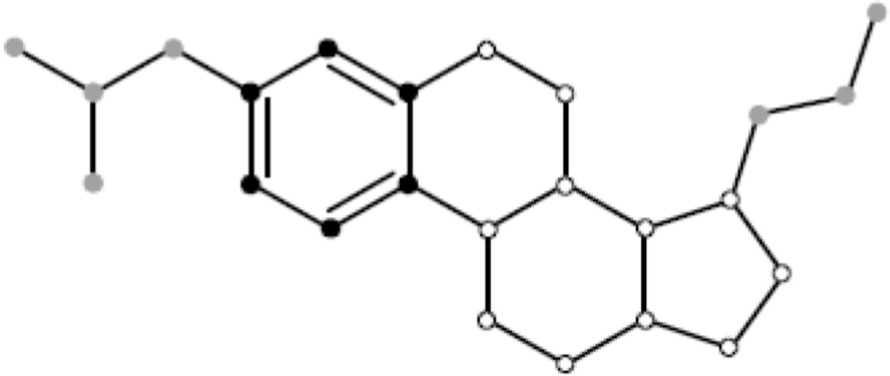


Carbon Types by ASTM D 2140 in a **single** molecule

= C in Paraffinic structure C_P = 32%

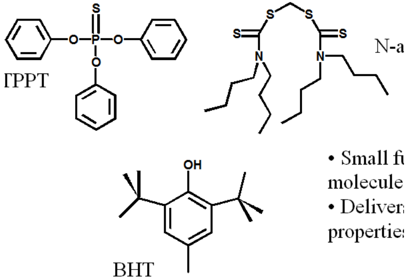
= C in Naphthenic structure C_N = 44%

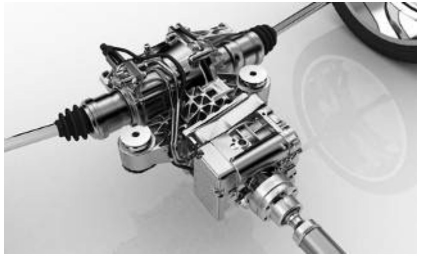
= C in Aromatic structure C_A = 24%

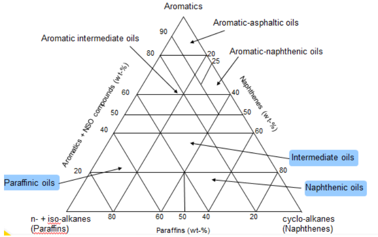


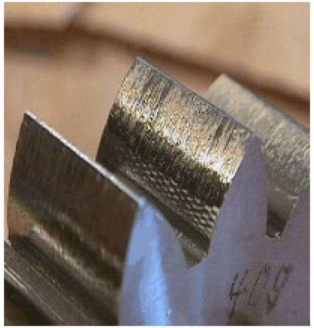
Base Oils, Additivs and Lubricants

- Tribology, the Science of…
  - Friction, Wear and Lubrication
  - …which is a hybrid of Chemistry, Physics and Mechanical Engineering





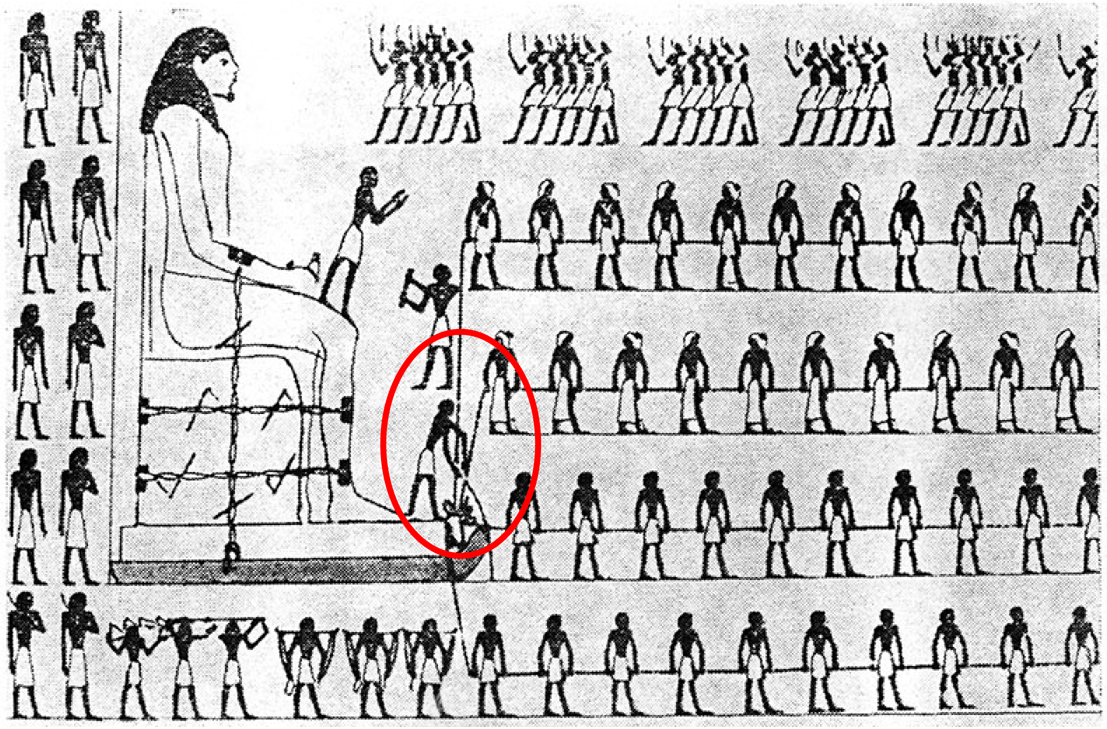




An Introduction to Lubricants

The History of Lubrication, Egypt 1880B.C.

- The World's First Tribologist in Art & in Action; King Djehutihotep's statue being pulled on an oil-lubricated sled



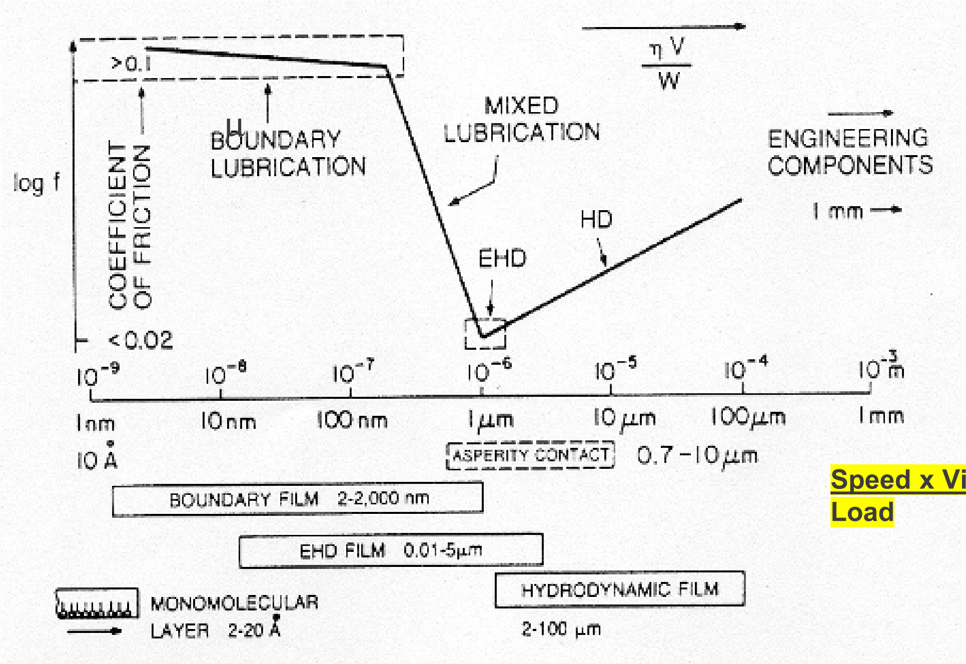
Leonardo da Vinci (1452-1519)

- ***"All things and everything whatsoever, however thin it be, which is in middle between object that rub together, lighten the difficulty of this friction"***

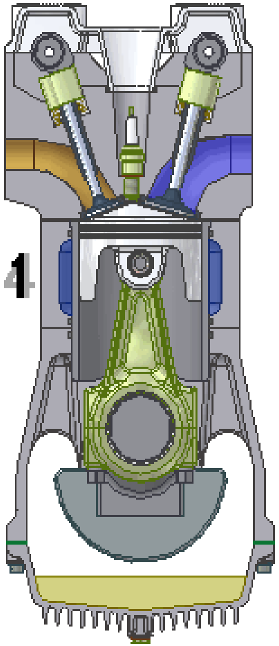
Lubricants & Tribology

Why Lubricants?

- **What is Tribology…..**
  - **The Stribeck Curve (1902)**



Speed x Visc.
Load



The purpose of lubricants

- Lubrication
  - Separate surfaces in contact
  - Reduce friction
  - Reduce wear
  - Prevent scuffing and galling (skärning)
- Other
  - Cooling
  - Corrosion protection
  - Prevent contaminants to enter into sensitive systems
  - Cleaning
  - Power transmission (traction drives) & wet brakes

Lube Fundamentals

Lubricant properties

Physical properties

Viscosity
Thermal properties
Temperature characteristics
Interfacial properties

Chemical properties

Total acid number
Total base number
Oxidation stability
Hydrolytic stability
Corrosion inhibition

Environmental properties

Biodegradability
Renewability
Toxicity
Bioaccumulation

Mineral

VHVI

PAO

Ester

PAG

Extreme Pressure

AntiWear

Friction Modifier

VI Improver

Pour Point Depressant

Anti Oxidant

Detergent

Dispersant

Corrosion Inhibitor

Antifoamant

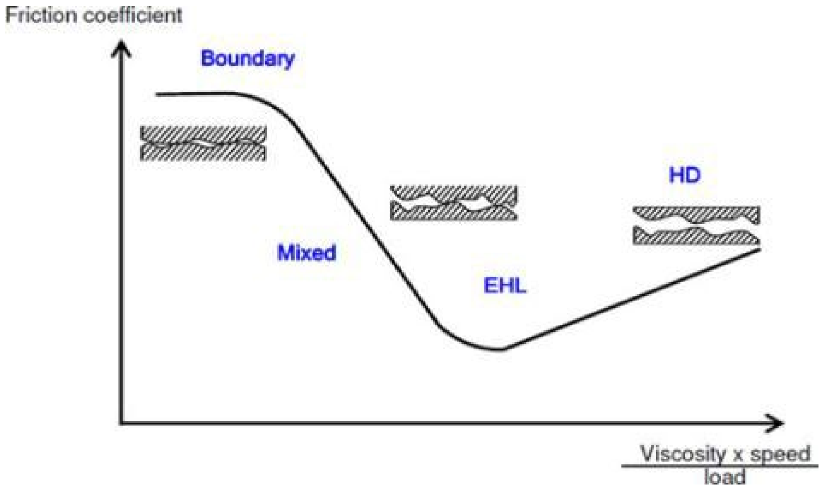
Cu passivator

Additives enhance the properties of the base fluids – more on that later!

Lubricant

The Stribeck Curve

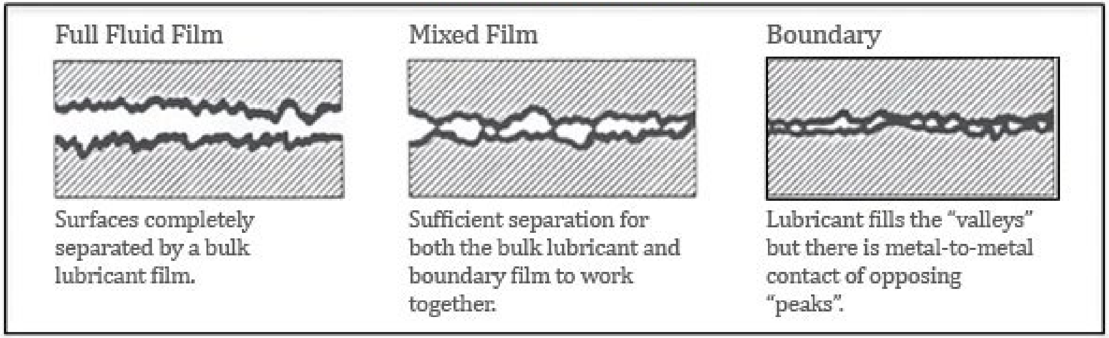
- The most useful model in all of Tribology!
- Indicates a simple relationship between
  - Dynamic viscosity
  - Sliding speed
  - Applied contact load
- Gives immediate directions and indications of the main contact conditions
- The Lubrication Regimes
- Whether the **fluid film** or **the tribo film**, formed by the additives, is the dominant factor of influence



Three Lubrication Regimes

- Full film lubrication, HydroDynamic (HD)
- Mixed Film Lubrication, ML
- Boundary Film Lubrication, BL

Figure 1: Lubrication Regimes



Three Lubrication Regimes – a useful concept

Full film lubrication (hydrodynamic lubrication, HD)

- Plain journal bearings in a turbine shaft

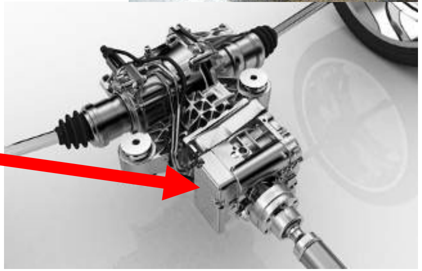
Mixed Film Lubrication (ML), a transition phase where the power of the additives and the properties of the fluid film interact strongly

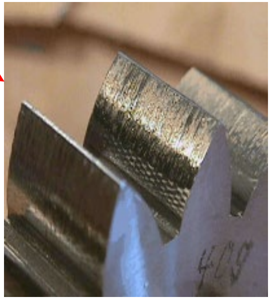
- Friction Phenomena in a lubricated Limited Slip Clutch

Boundary lubrication (boundary Lubrication)

- Phenomena between tex. Gear flanks in a gearbox
- The additives and their reaction products dominate this Regime

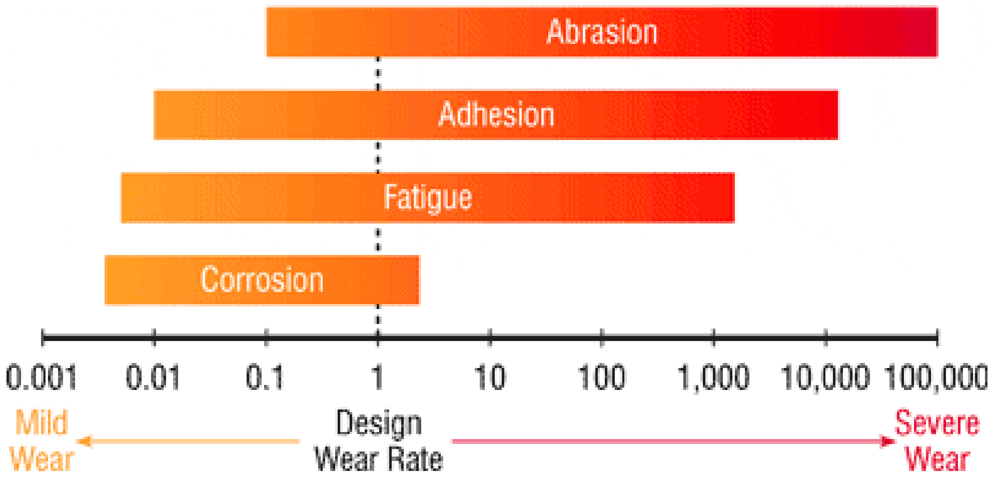
If you Say "Lubrication Regime", the World will perceive you as a Tribologist!





Different wear rates

- The different wear mechanism usually result in wear rates of different magnitude
  - Mild wear- Severe wear –Catastrophic wear



Lubricity and friction
Dr. Boris Zhmus, Bizol

THE 2021 EUROPEAN BASE OILS & LUBRICANTS SUMMIT

17th & 18th November, 2021 - Amsterdam, The Netherlands

ACI

NYNAS

A Novel Class of Biobased Organic Friction Modifiers Revealing the Superlubricity Effect

Boris Zhmud, BIZOL Germany GmbH

Arthur Coen, Karima Zitouni, Ward Huybrechts, Philippe Blach, Anne-Elise Lescoffit, OLEON s.a.

BIZOL

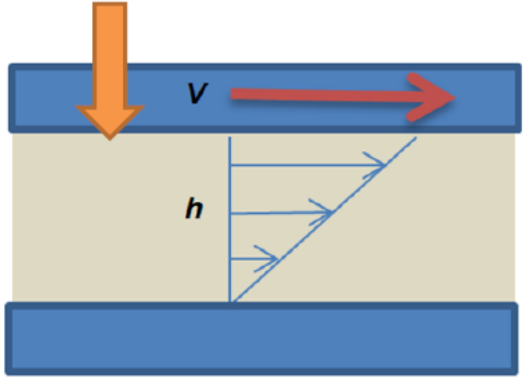
oleon
a natural chemistry

1

How do friction modifiers work?

Boundary slip

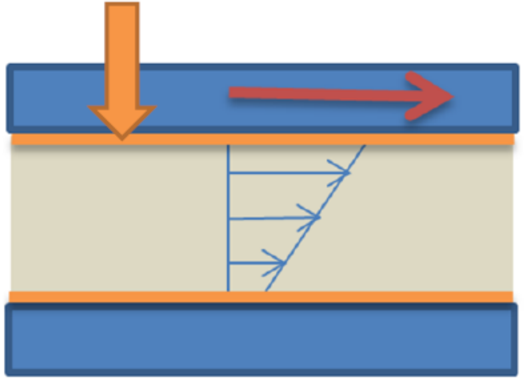
The excess interfacial energy (oil-metal) is high



Laminar flow of lubricant between two surfaces. No boundary slip. Velocity gradient is V/h.

No boundary slip: V(0) = V(h) = 0
Lubricant sticks to the surface, a sort of molecular anchoring.

The excess interfacial energy (oil-metal) is low



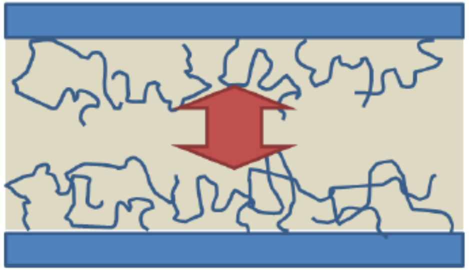
The same in the presence of friction modifier. Boundary slip is possible. Velocity gradient is reduced.

Boundary slip: V(0) = V(h) > 0
Lubricant doesn't stick to the surface.

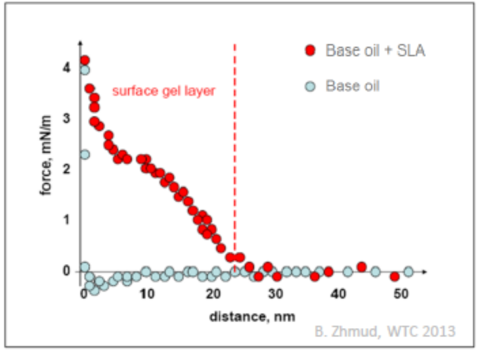
How else do friction modifiers work?

Disjoining pressure

Surfaces are repelled from each other due to elastic compression of polymer



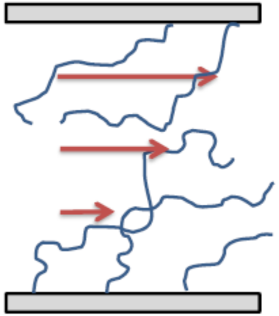
AFM Measurements Showing the Repulsive Force Exerted on the AFM Tip by the Surface Gel Layer Formed by Adsorption of a Surface-Active Block-Copolymer Superlubricity Additive



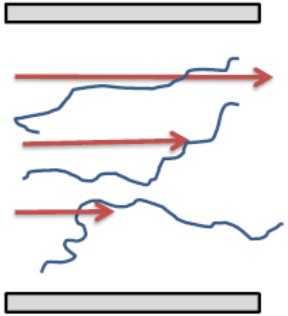
Complex viscosity of the lubricant film due to adsorbed polymeric friction modifier

$$\eta = \eta' + i\eta''$$

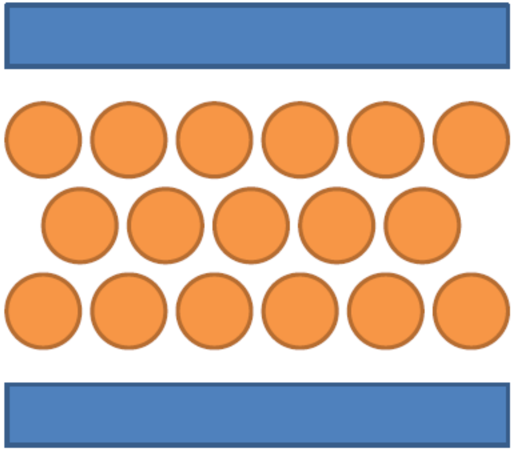
Low shear
Quasi-full-film conditions
Strained adsorbed OFM
Dominant Im(η) contribution



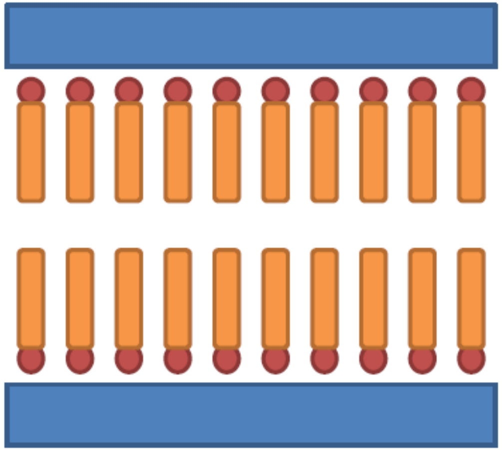
High shear
Mixed lubrication conditions
Desorbed OFM molecules
Dominant Re(η) contribution



Molecular aspects



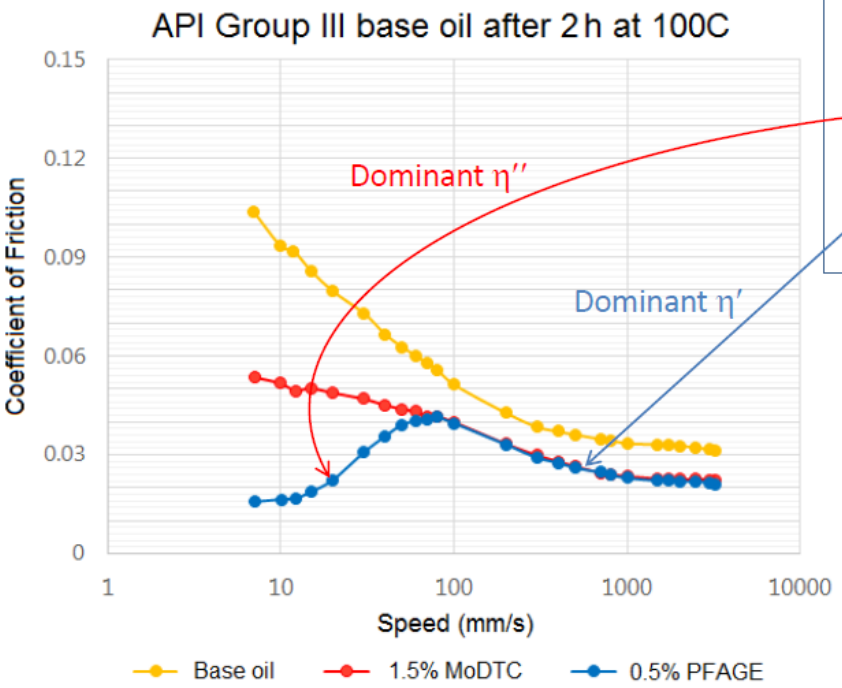
Isotropic molecular structure,
No preferred orientation near
the surface

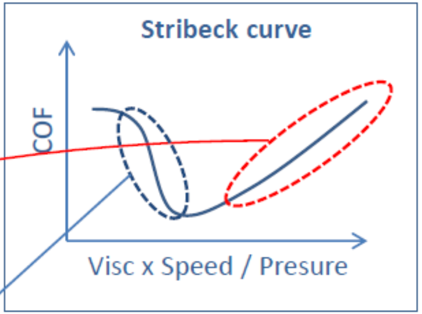


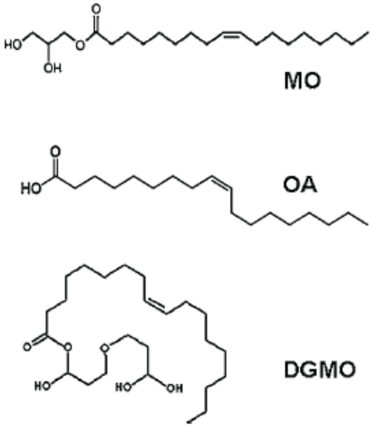
Anisotropic molecular structure,
Preferred orientation near
the surface

- ✓ Adsorbed layers reveal elasticity (non-Newtonian rheology)
- ✓ Adsorbed layers create repulsion

PFAGE OFMs



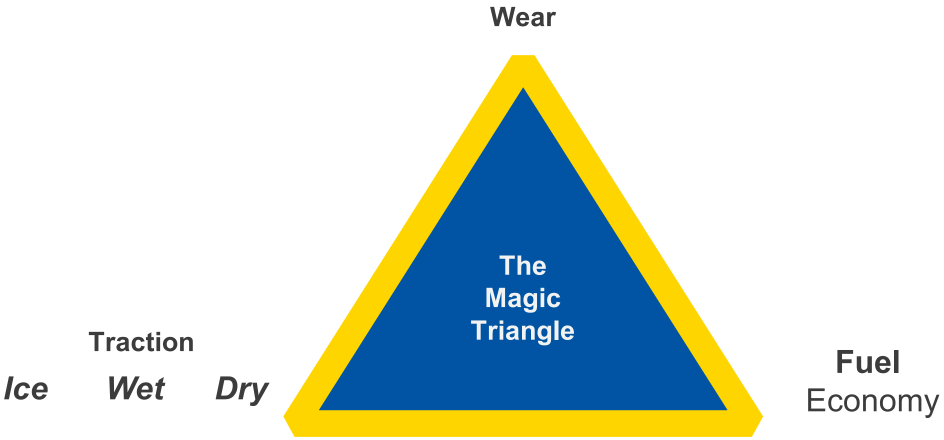


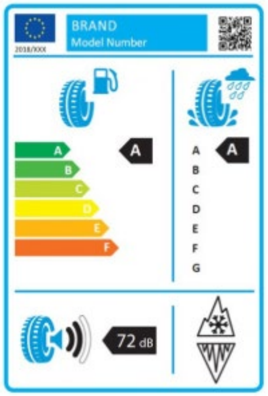


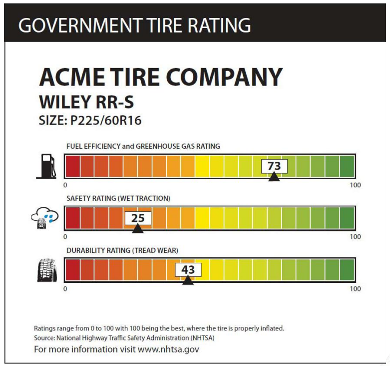
Increase in HLB favor adsorption to metals

Friction in tyres and on the road
Dr. Kamyar Alavi, Nynas AB

The magic triangle … or square … or Pentagon





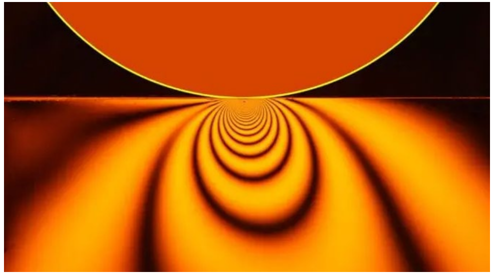


- Key properties of tyres from an end consumer perspective
- Improvement not always aligned between different properties
  - Optimisation needed
- Highly dependent on compound design
  - Viscoelastic properties dictate traction and fuel economy

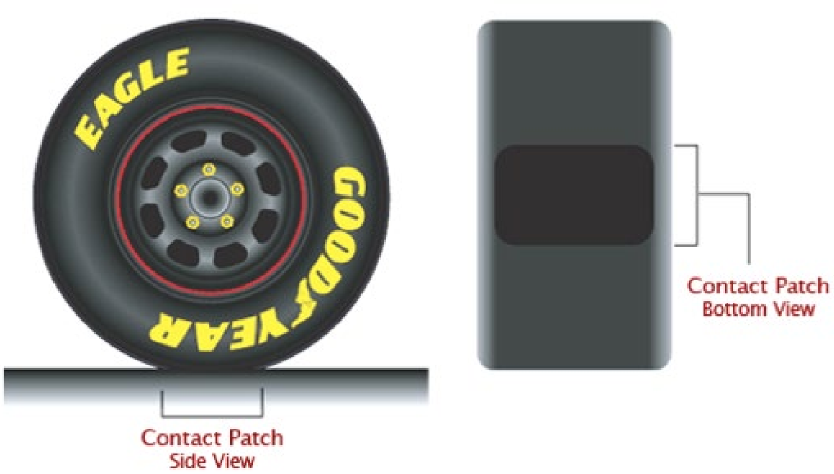
Friction vs Adhesion

Friction-dominated processes

- Temporary contact
  - Both rubber and substrate surface can change
  - Loss of contact due to external factors
    - Oil spill on surface
    - Water planning
    - Too low friction coefficient
- Tyre - road interface
  - More complex but friction dominated
  - Deformation- rolling resistance
  - **11% of energy loss well-to-wheel (!)**
- Door stopper – floor interface



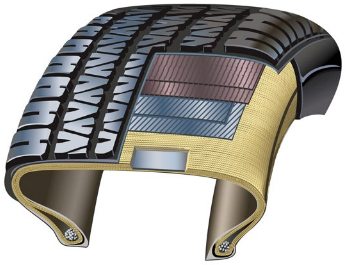
Cylinder-on-flat, Hertzian deformation



Friction vs Adhesion

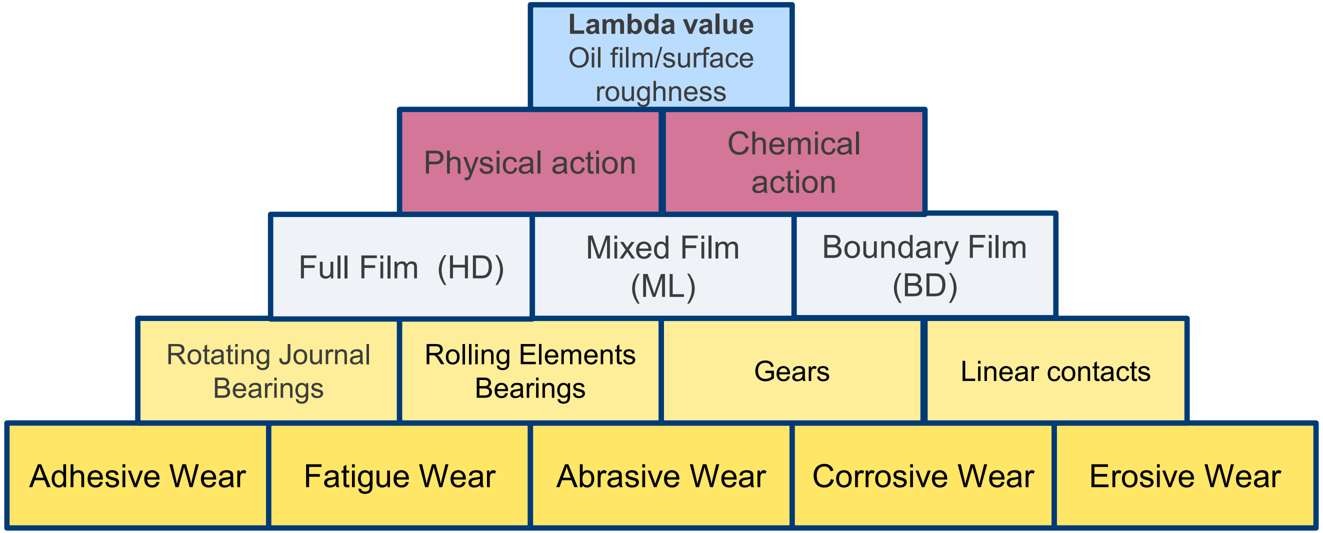
Adhesion-dominated processes

- "Permanent" contact
  - The two surfaces are chemically bonded to one another
  - Loss of contact due to internal factors
    - Rubber formulation ➔
      - Unwanted oil migration to interlayer surface
    - Loss of interlayer bonds ➔
      - Ageing;
      - too weak adhesion etc



- Certain parts in tyre construction
  - Rubber coated steel cord belts
- Rubber metal assembly
  - Vibration dampers
  - Tools

The “Frelin Maya Pyramid” - the Building Blocks of Modern Lubrication Technology



Solutions for the transition to a sustainable society