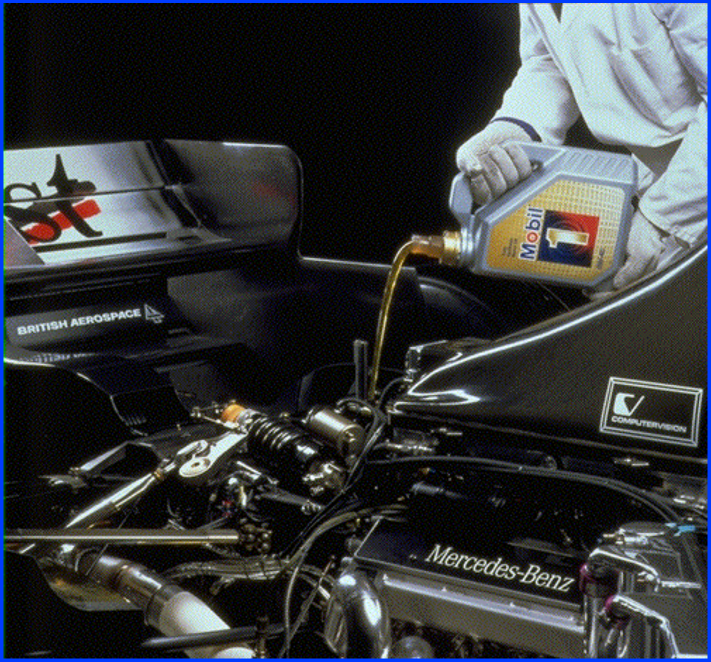
Fundamentals of Lubrication



Lubricants

Summary

The Role of the Lubricant

Lubricant Composition and Use

Functions of Engine Lubricants

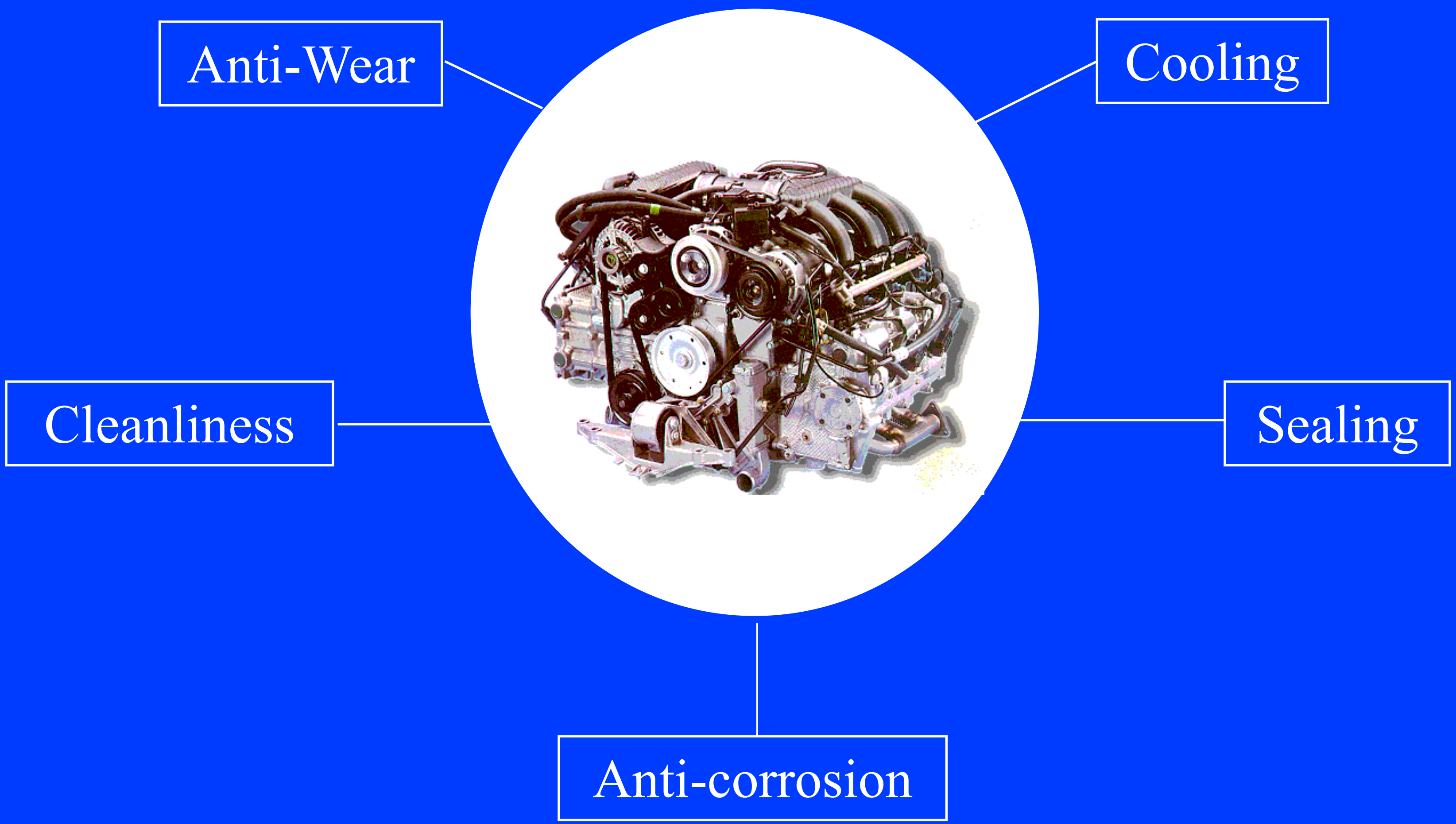
Lubricant Properties

- Physical/Chemical
- Service Behavior
- Classifications

Most principles discussed in this presentation apply to other lubrication applications such as industrial oils, gear oils, etc.

Engine Lubricants

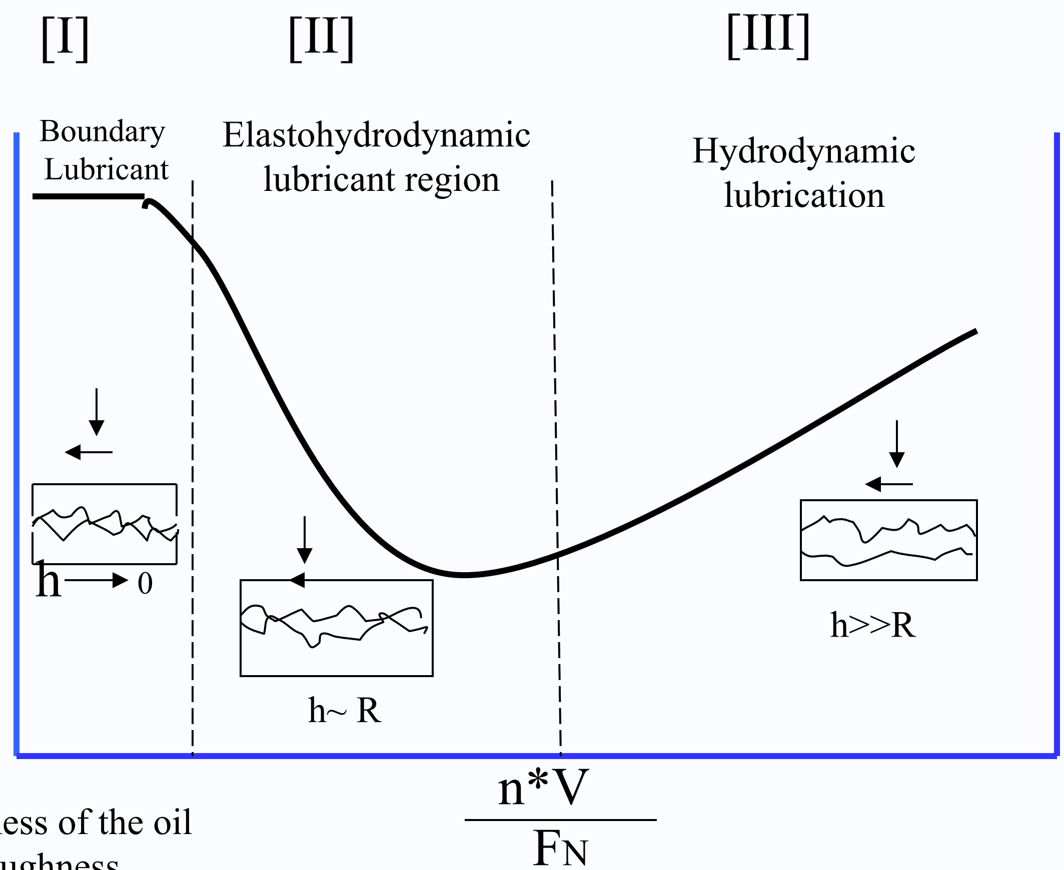
Engine Oil Functions



The Function of Lubricants and Lubrication

- **Lubrication**
  - Separates surfaces in contact
  - Reduces friction
  - Reduces wear
  - Prevents scuffing and galling
- **Other functions**
  - Cooling
  - Corrosion protection
  - Prevents contaminants from entering into sensitive system
  - Cleaning
  - Power transmission (traction drive)

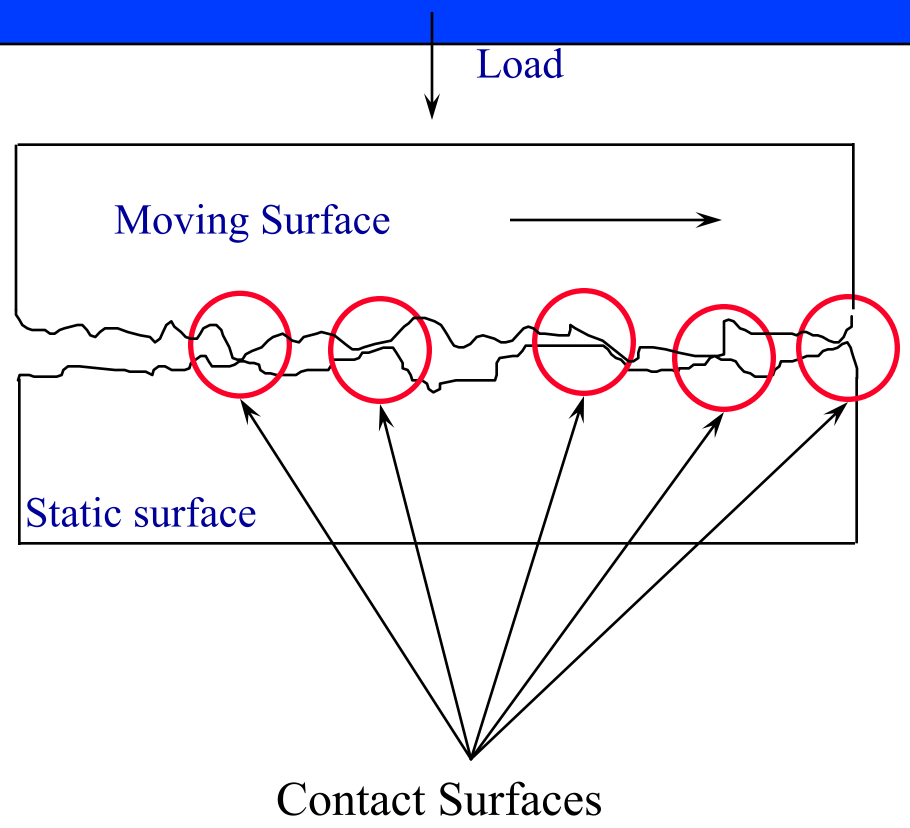
Stribeck curve and lubrication regions



h= the thickness of the oil
R= surface roughness
F= friction coefficient
V= viscosity
F_N = load

Lubricants

Friction



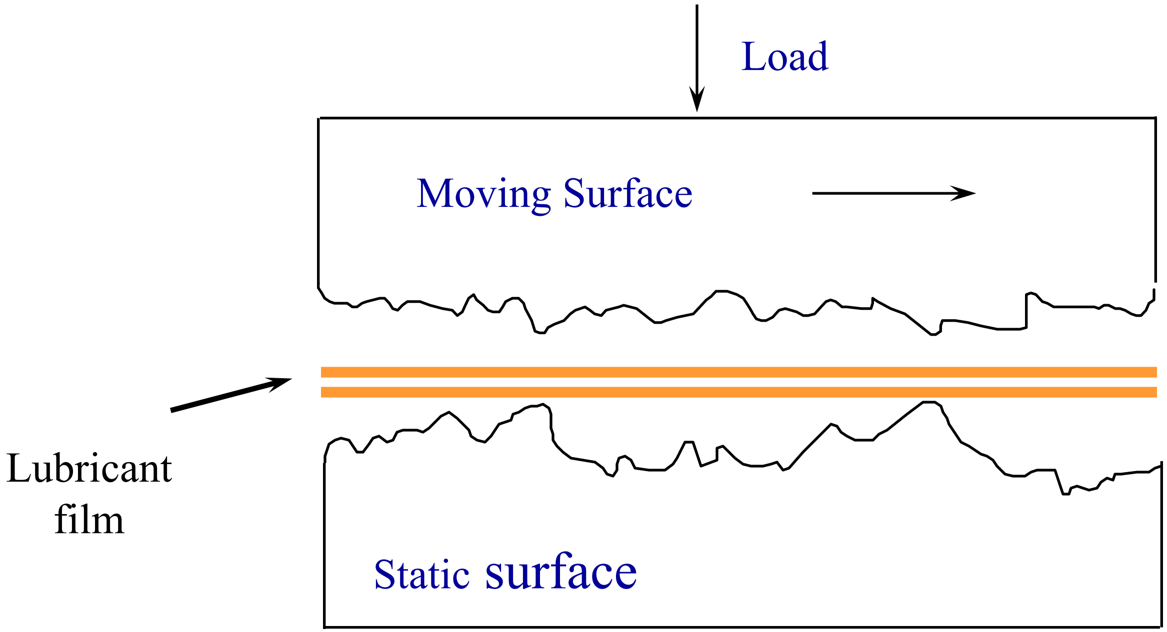
Contact between two uneven surfaces in relative motion generates microwelding and wear

Friction

- Caused by relative motion between surfaces
- Heat generation = lube instability = surface damage
- Types of Friction:
  - Static
    - Can cause “stick-slip ”
  - Sliding
    - “Classic” friction
  - Rolling
    - Lower friction than rolling

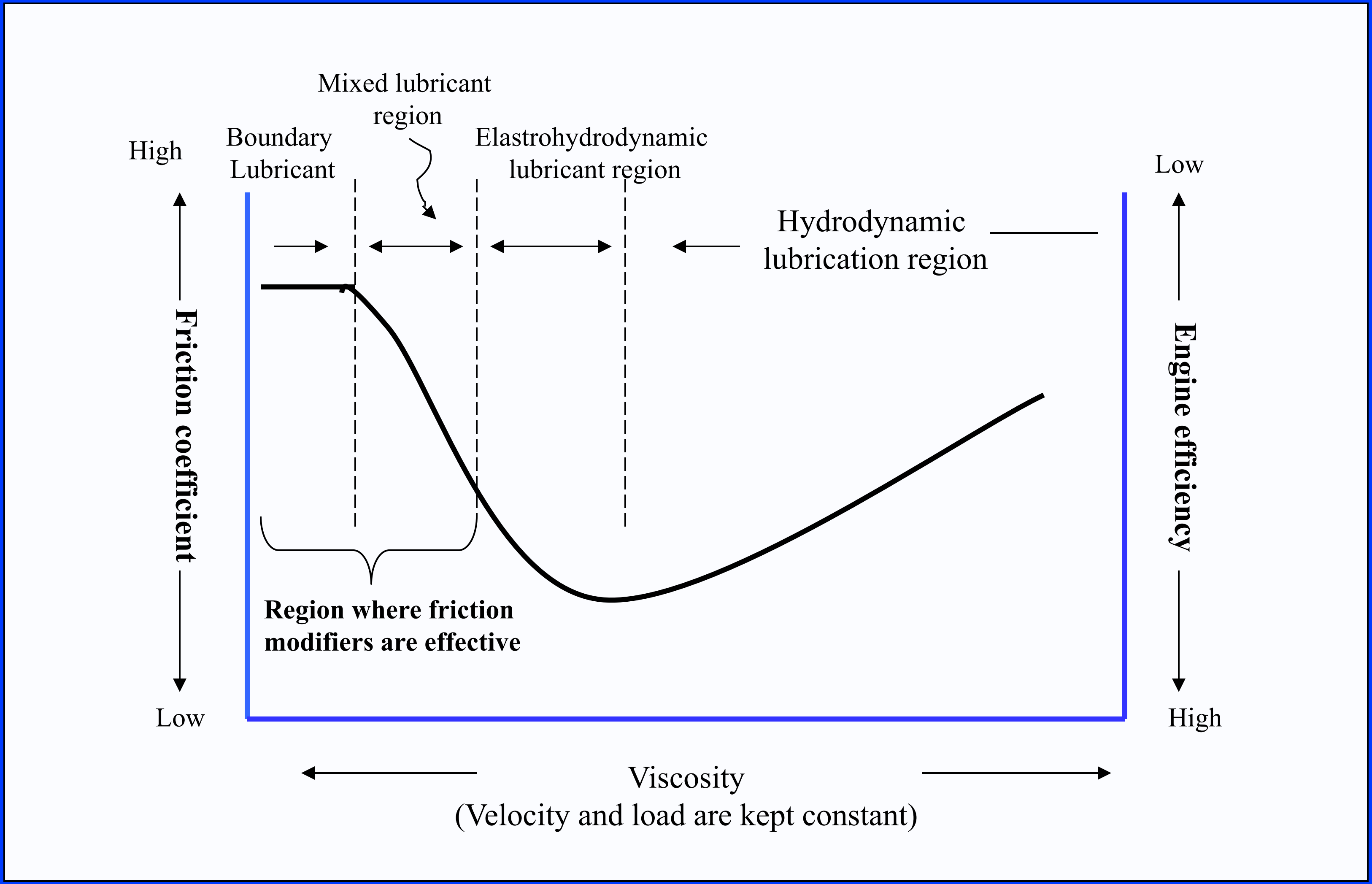
Lubricants

Friction



Oil film thickness greater than surface microtexture

Relationship between Stribeck curve and friction modification



What Are Friction Modifiers?

Surface active chemicals that affect friction coefficient under boundary lubrication conditions

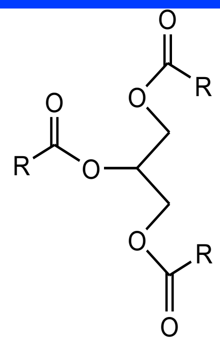
Almost all chemicals fit this broad definition

For our purposes:

Chemicals that, when added to a lubricating oil at a concentration less than 1%, significantly affect the coefficient of friction

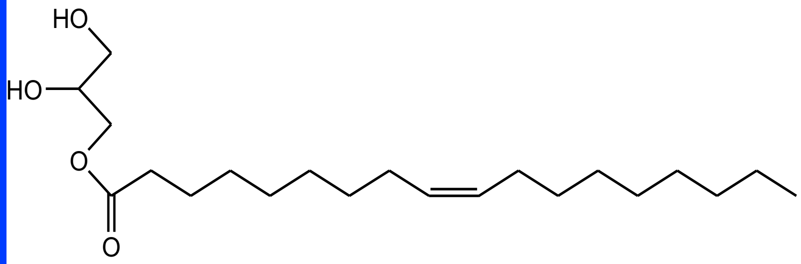
e.g. glycerol mono-oleate (GMO)

Organic friction modifiers

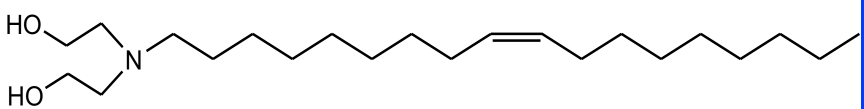


R = C14 to C20 (saturated)

Triglycerides



Glycerol monooleate



Ethoxylated fatty amine

Lubricants

Composition

Basestocks used in engine lubricants can be:

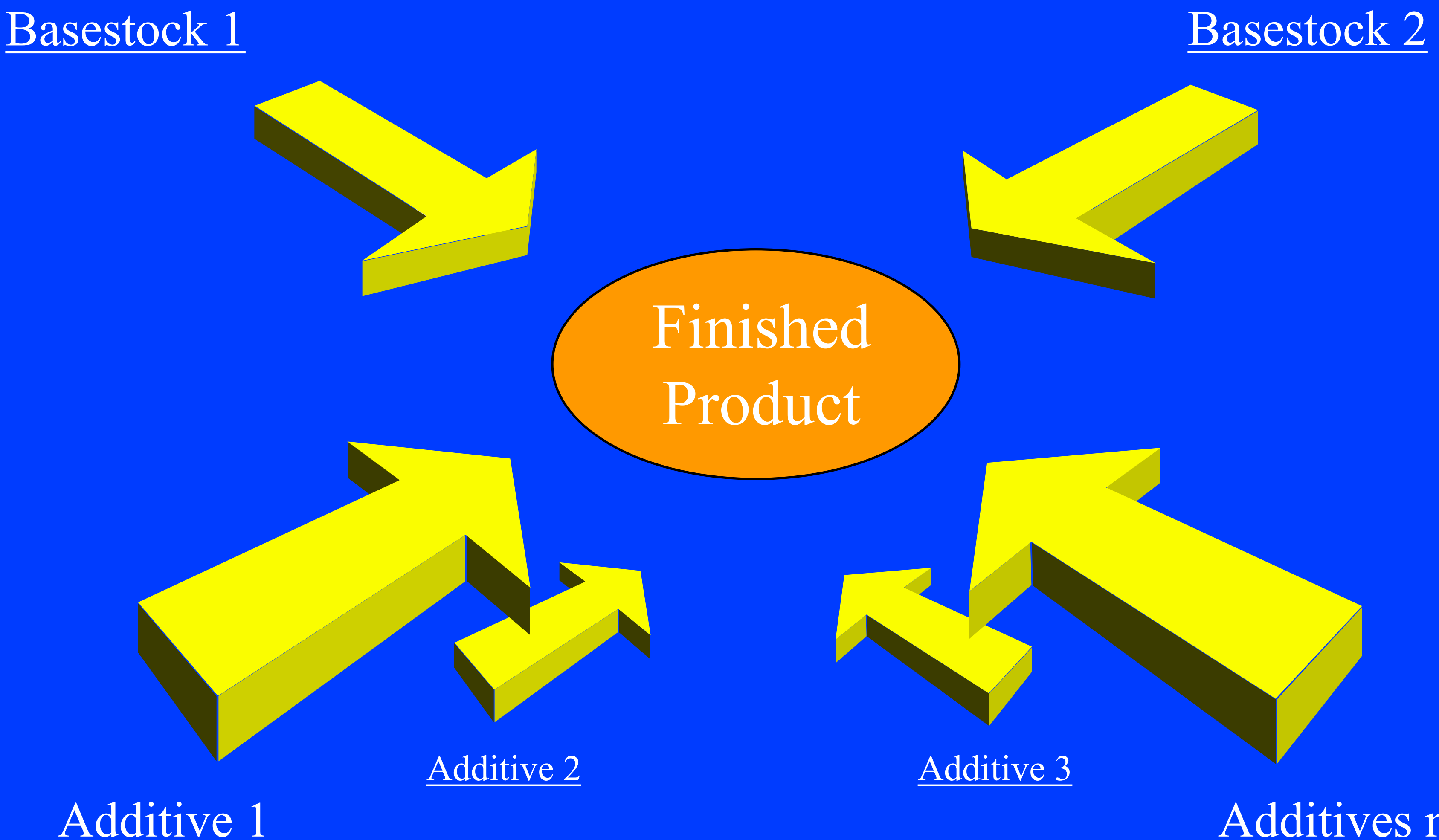
- Mineral oil based
- Synthetics
- Semi-Synthetics

Additives are divided in 3 main types:

- Surface protection additives
- Performance additives
- Oil protection additives

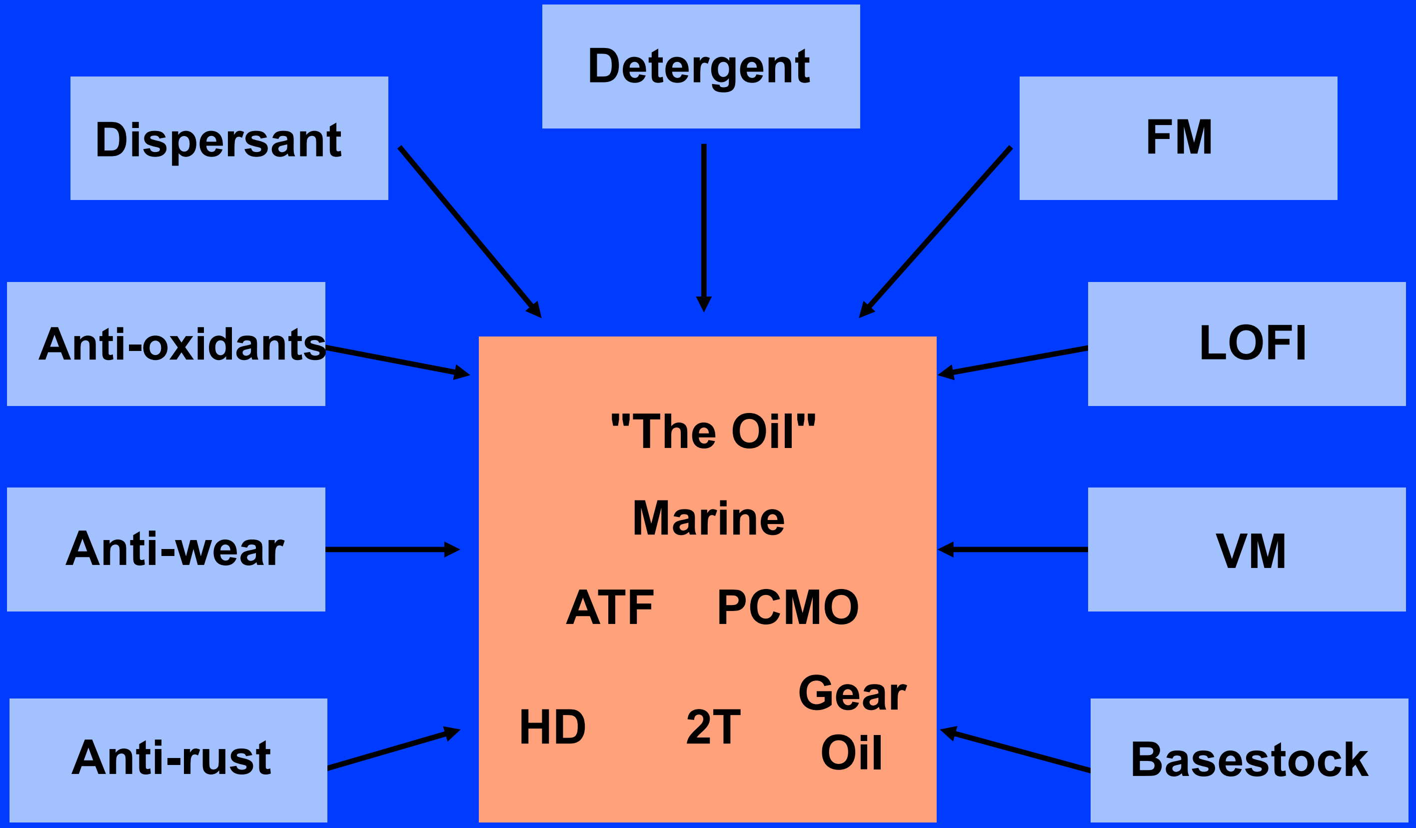
Lubricants

Composition



The Key is Balancing the Additives for the Application

Formulation Science



Group I

Mineral Oil Basestocks

Obtained from crude by distillation

Refined using historical techniques
- solvent extraction
- solvent dewaxing
- hydrofining to reduce sulfur content

Removal of:
- Asphalt
- Light Paraffin's
- Wax
- Other undesirable components

It's an imperfect process, because a variety of different sized molecules are obtained.

API Group	Sats,%	Sulfur,%	VI	Typical Manufacturing Process
I	<90	>0.03	80-119	Solvent Processing

Group II

Mineral Oil Basestocks

Obtained by various processes

Mildly hydrocracked mineral oils
- solvent extraction
- solvent dewaxing
- more hydrofining to further reduce sulfur content
- saturation of some aromatics and olefins

API Group	Sats,%	Sulfur,%	VI	Typical Manufacturing Process
I	<90	>0.03	80-119	Solvent Processing
II	>90	<0.03	80-119	Hydroprocessing

Group III

Mineral Oil Basestocks

Obtained by various processes

Severely hydrotreated mineral oils

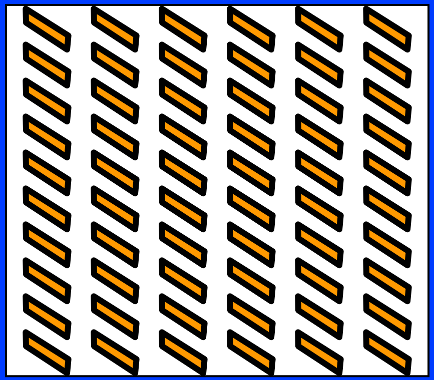
- Saturation of almost all aromatics and olefins.

API Group	**Sats,%**	**Sulfur.%**	**VI**	**Typical Manufacturing Process**
I	<90	>0.03	80-119	Solvent Processing
II	>90	<0.03	80-119	Hydroprocessing
III	>90	<0.03	120+	Wax Isomerization, H.C, GTL

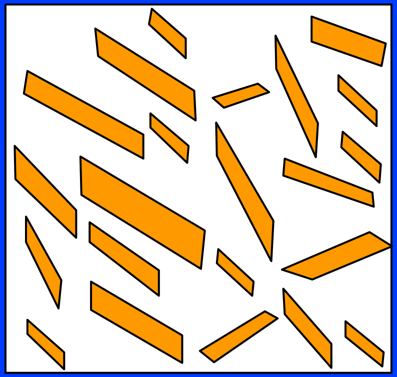
Group IV Polyalphaolefins (PAO)
(SpectraSyn, SpectraSyn Plus, SpectraSyn Ultra)

Synthetic	Mineral Oil
Pure compounds (no wax or impurities) Tailored properties	Complex mixtures Compromise among properties

SpectraSyn Synthetic Molecular Structures



Mineral Oil Molecular Structures



Groups V and VI

Group V *

All other basestocks not meeting Group I - IV definitions
i.e. esters (Esterex), alkylated naphthalene (Synesstic)
polyalkylene glycols, polyethers etc

Group VI

PolyInternalOlefins (PIO) - Europe Only

API Group	Sats, %	Sulfur,%	VI	Typical manufacturing Process
I	<90	>0.03	80-119	Solvent Processing
II	>90	<0.03	80-119	Hydroprocessing
III	>90	<0.03	120+	Wax Isomerization, H.C, GTL
IV	n.a	n.a		Polyalphaolefins (PAO)
V				All Other Basestocks

* Excellent reference "Synthetics, Mineral Oils, and Bio-Based Lubricants" L.R. Rudnick, Ed., CRC Press, 2004

Definition of a Synthetic Basestock

Others

Group III basestocks are considered synthetic and manufactured by hydrocracking and isomerizing slack wax. They generally have more than or equal to 120 VI with more than or equal to 90% saturates and less than or equal to 0.03% sulfur.

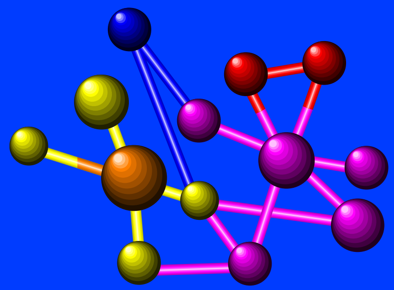
ExxonMobil

Synthetic lubricants are manufactured in chemical plants by reacting components and are specifically designed to possess physical and performance characteristics that are superior to mineral oils. As a result, the molecular structure of synthetic lubricants can be precisely arranged to meet, and often exceed, manufacturers' criteria for high-performance equipment.

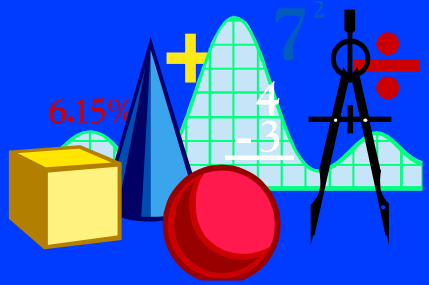
Lubricants

Synthetic Basestocks

Derived from molecules which yield basestocks with high purity and excellent stability



Synthetic basestocks have excellent service behavior and are free from the many mineral oil constraints.



New Specifications Make Synthetics Popular

- New engine oil specification
  - API SM / ILSAC-GF4 (USA)
  - ACEA 2004 (EU)
- Emission reduction
- Fuel economy
- Marketing of premium brands
- Require tailor- made lubricants in total or blended with mineral oils to meet tighter specifications.

Additives

Surface Protection Additives

- Anti-Wear and EP agents
- Corrosion and rust inhibitors
- Detergents
- Dispersants
- Friction modifiers

Performance Additives

- Pour point depressants
- Seal-swell controllers
- Viscosity modifiers

Oil Protection Additives

- Anti-foam
- Anti-oxidants
- Metal de-activators
- Demulsifiers

Lubricant Characteristics

- Viscosity
- Viscosity Index
- Low temperature fluidity
- Flash point
- Oxidation stability
- Thermal stability
- Detergency
- Dispersancy
- Alkalinity
- Anti-Wear
- Anti-Rust and Anti-Corrosion
- Ash content

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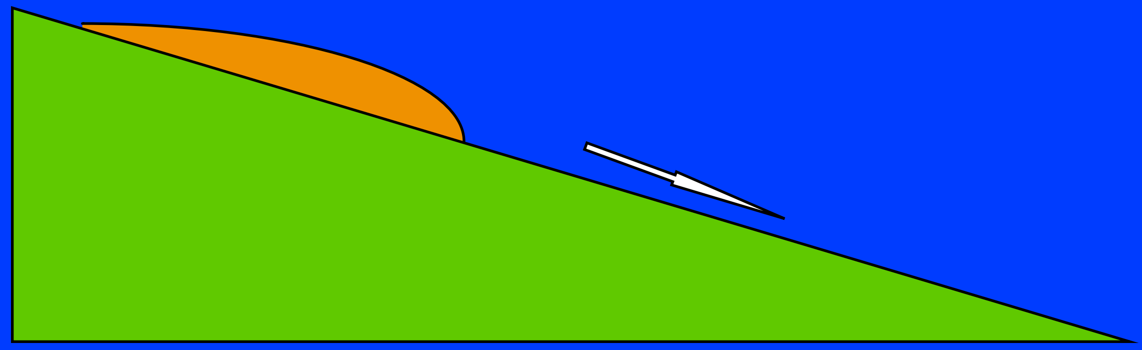
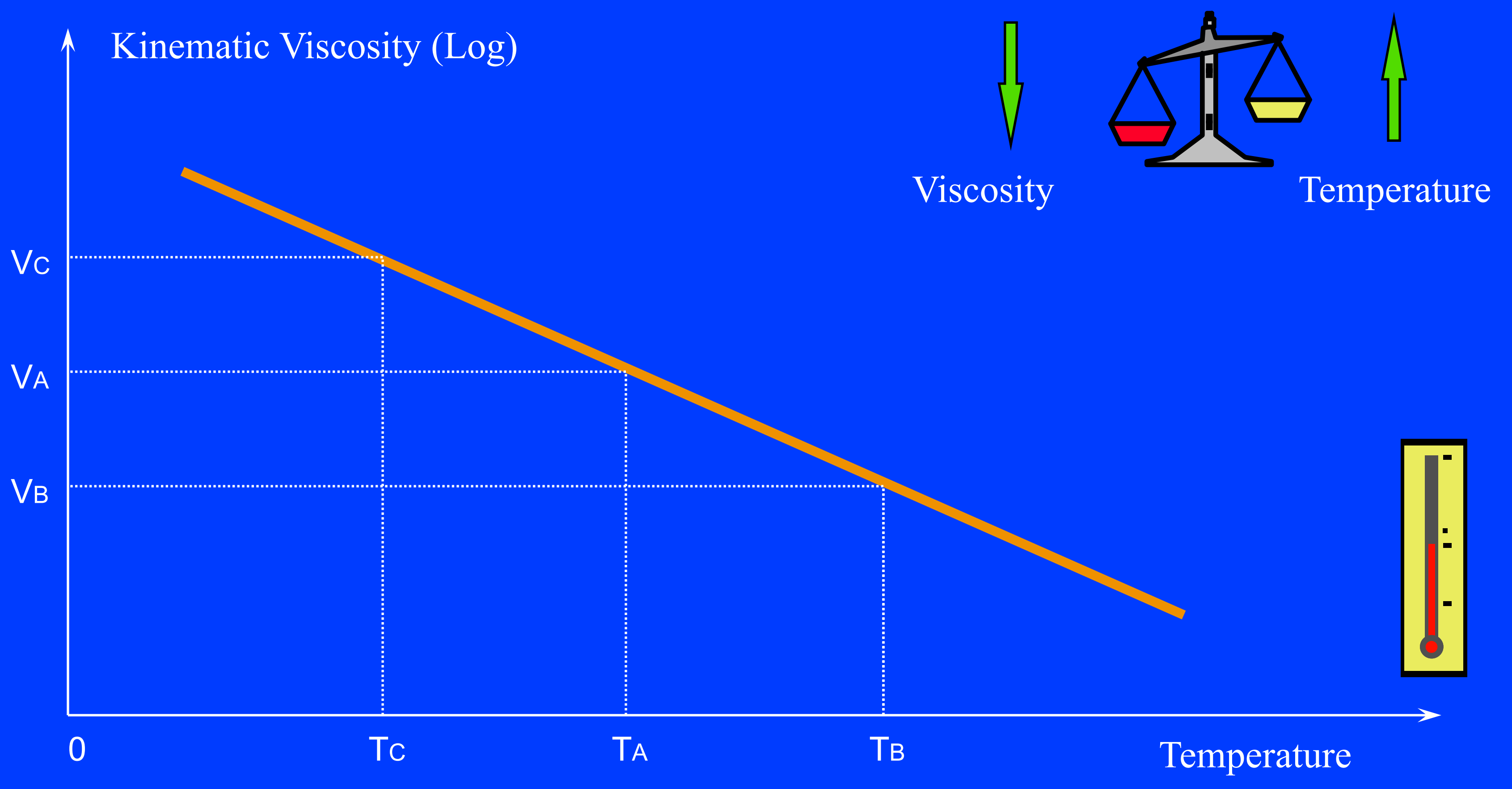
What is Viscosity?

Viscosity:
Measure of a fluid's internal resistance to flow at a given temperature



Viscosity Is a Function of Temperature



Viscosity Units

- ✓ Viscosity Types

Kinematic : expressed in Stoke (St) or Centistoke (cSt) (1 cSt = 0.01 St = 1 mm^2/s)

Dynamic Viscosity = Density x Kinematic Viscosity

Dynamic : expressed in Poise (P) or Centipoise (cP) (1 cP = 0.01 P = 1 mPas)

- ✓ Other Viscosity Units

S.S.U. : American unit

Redwood : British unit

SAE : Engine Oil Viscosity Classification

Making the right choice for oil viscosity

If Viscosity is too	May result in
Low	Increased wear
Low	Increased oil consumption
Low	Increased oil leaks and noise
High	Increased operating temperature and reduced output power and poorer fuel economy

Correct basestock Grade will yield better cold starting, reduce metallic wear, oil consumption and power losses by fluid friction, as well as reduced deposit formation and oil leaks in sealed joints

Lubricant Characteristics

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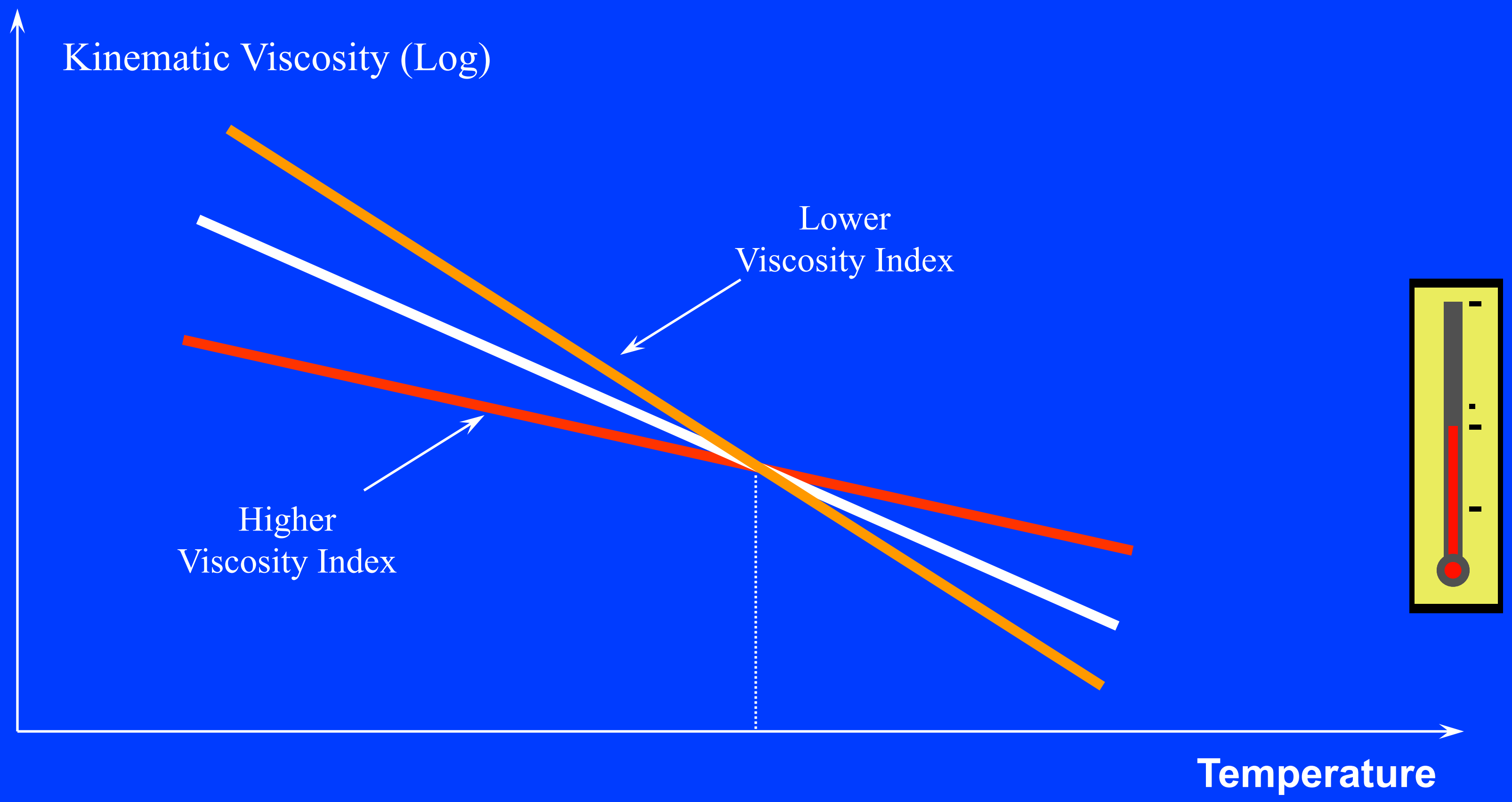
Viscosity Index

Measures the change in viscosity of a fluid with
a change in temperature



Viscosity Index

Lubricant with high V.I. guarantees

Adequate oil film in all
working conditions

This means:

- ✓ Prevention against wear (higher viscosity at high temp)
- ✓ Low oil consumption
- ✓ Better oil flow at lower temperatures (lower viscosity at low temp)

Viscosity Classification

Physical Requirements for Engine Oils: SAE J300 Table

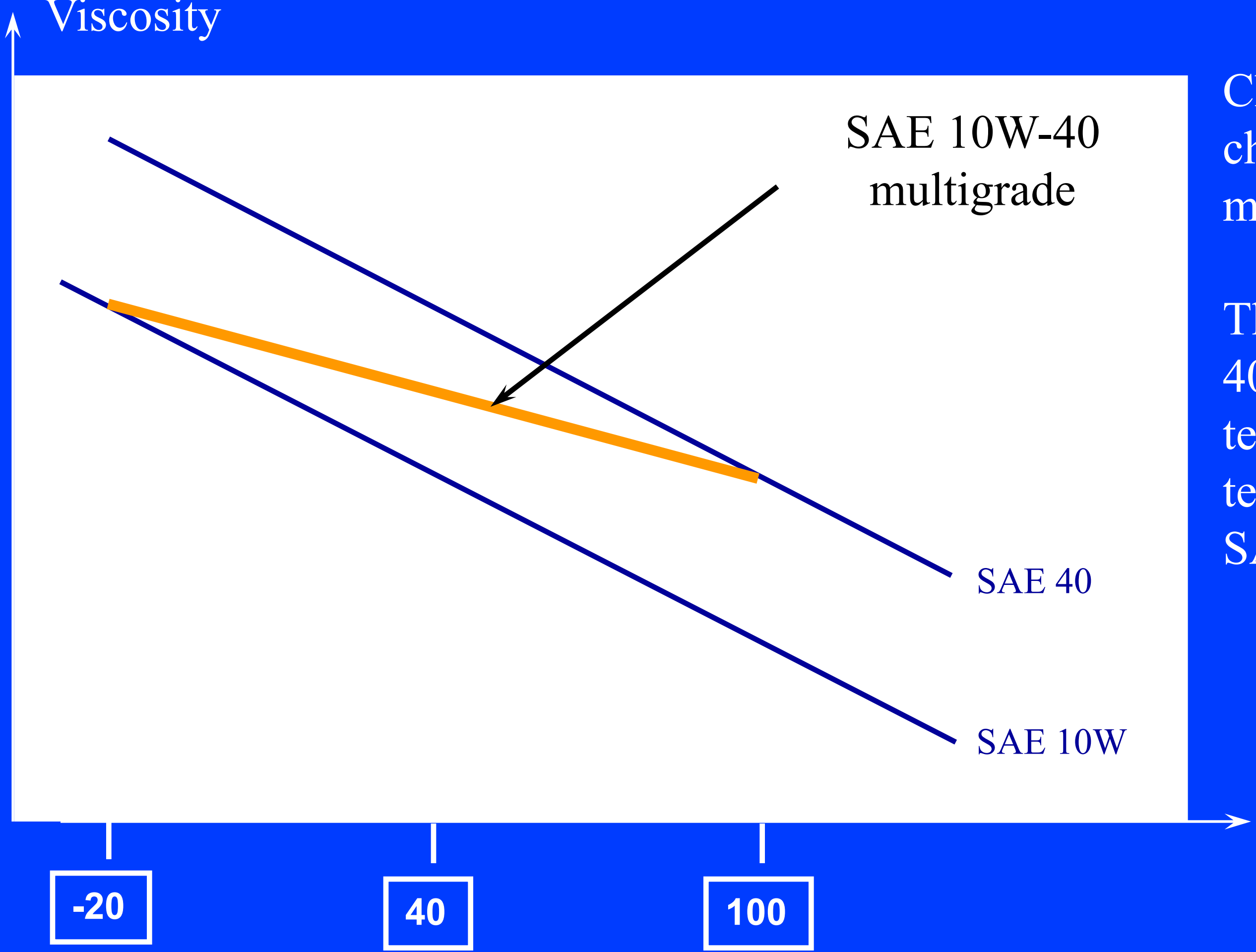
SAE Viscosity Grade	Cranking (cP) max at temperature ºC, measured in CCS	Pumping (cP) max. With no yield stress at temperature (ºC)	Kinematic Viscosity (cSt) at 100 ºC Mín	Kinematic Viscosity (cSt) at 100 ºC Max	High Shear Rate (cP) @ 150 º C min
0W	6200 @-35 ºC	60,000 @ -40 ºC	3.8	-	-
5W	6600 @-30 ºC	60,000 @ -35 ºC	3.8	-	-
10W	7000 @-25 ºC	60,000 @ -30 ºC	4.1	-	-
15W	7000 @-20 ºC	60,000 @ -25 ºC	5.6	-	-
20W	9500 @-15 ºC	60,000 @ -20 ºC	5.6	-	-
25W	13,000 @-10 ºC	60,000 @ -15 ºC	9.3	-	-
20	-	-	5.6	<9.3	2.6
30	-	-	9.3	<12.5	2.9
40	-	-	12.5	<16.3	2.9(1)
40	-	-	12.5	<16.3	3.7(2)
50	-	-	16.3	<21.9	3.7
60	-		21.9	<26.1	3.7
	(1) 0W-40,5W-40, 10W-40 grades	(2) 15W-40, 20W40, 25W-40, 40 grades			

1 cP = 1 mPa.s   1 cSt = 1 mm2/s   CCS = Cold Cranking Simulator

Viscosity

Flexibility of multigrades; Example

Viscosity



Temperature (ºC)

Chart shows Visc. / Temp. characteristics for two monogrades.

The multigrade has the SAE 40 properties at high temperatures and the low temperature properties of a SAE 10W

Viscosity Classification for Industrial Oils

ISO Viscosity Classification			
ISO Viscosity Grade (ISO VG)	Kinematic Viscosity cSt @ 40°C (104°F) midpoint	Kinematic Viscosity Limit cSt @40°C (104°F) minimum	Kinematic Viscosity Limit cSt @40°C (104°F) maximum
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	9.00	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	90.0	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
2200	2200	1980	2420
3200	3200	2880	3520

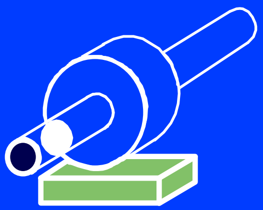
1 cSt = 1 mm^2/s

Lubricant Characteristics

- Viscosity
- Viscosity Index
- Low temperature fluidity
- Flash point
- Oxidation stability
- Thermal stability
- Detergency
- Dispersancy
- Alkalinity
- Anti-Wear
- Anti-Rust and Anti-Corrosion
- Ash content

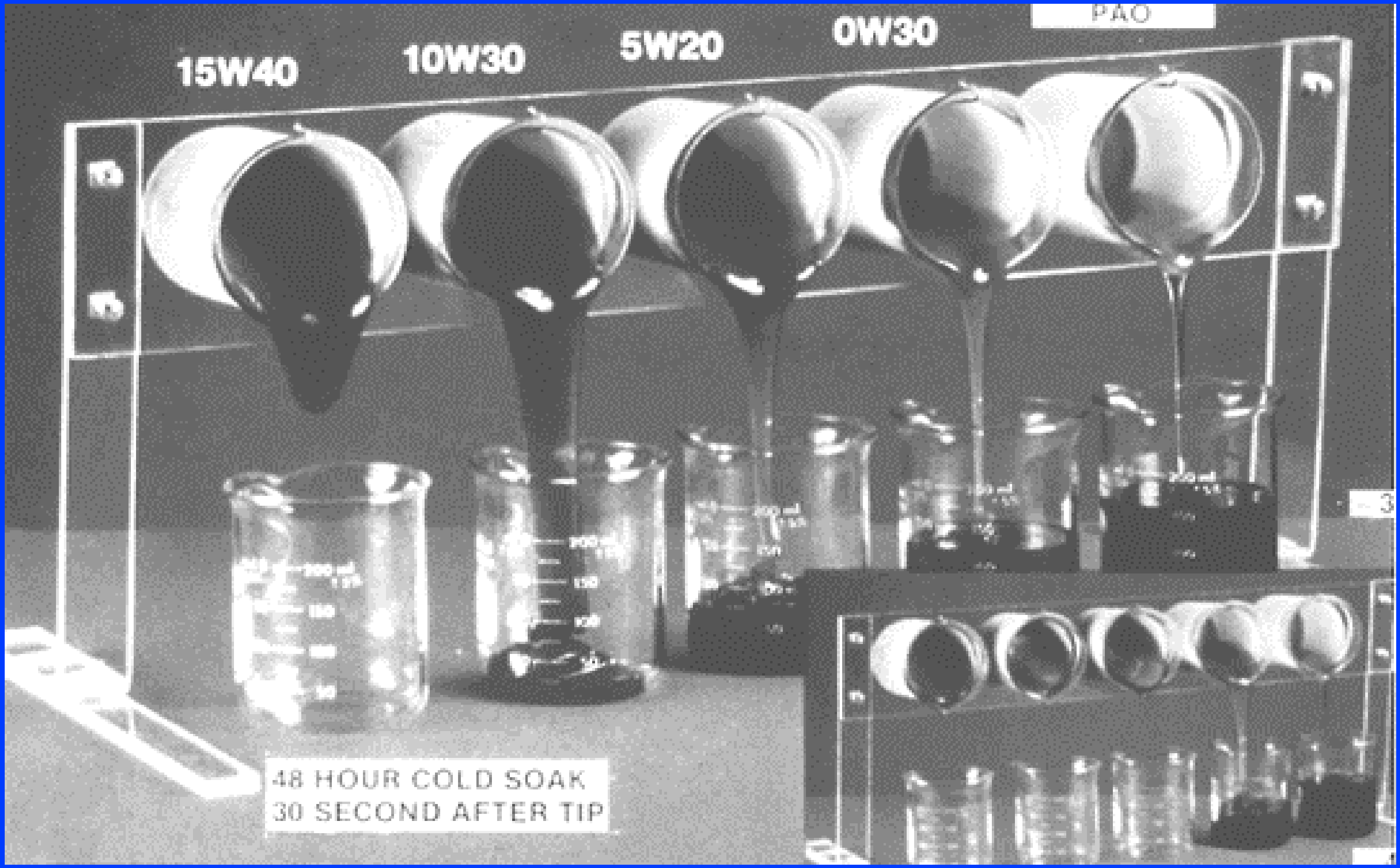
Low Temperature Fluidity

Guarantees immediate oil flow
to the engine moving parts
at low temperatures



Minimum pumping temperature:
Proper lubrication at low temperatures is critical for engine life. The lower the temperature an oil can flow through the oil pump, the better the engine is protected.

☞ Synthetics have much better low temperature fluidity than mineral based oils; do not contain wax.


15W40
10W30
5W20
0W30
PAO
48 HOUR COLD SOAK
30 SECOND AFTER TIP

Lubricant Characteristics

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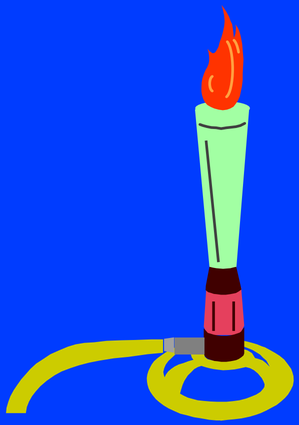
Flash Point

Temperature at which vapor from a heated oil ignites when exposed to a naked flame.



- Important indicator of the fire and explosion hazards associated with petroleum products.
- Gives information about volatility, measure of an engine oil´s tendency to evaporate at high engine temperatures.

Lubricant Characteristics

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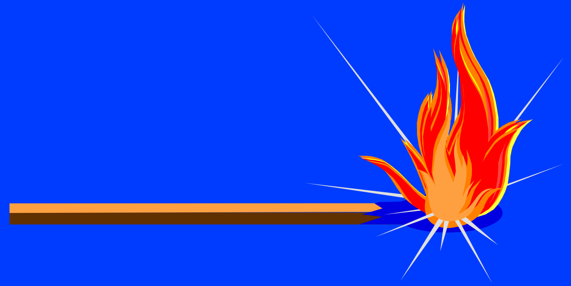
Oxidation Stability

Oxidation occurs when oxygen attacks petroleum fluids.

The process is accelerated by heat, light, metal catalysts and the presence of water, acids, or solid contaminants.

Oxidation leads to:

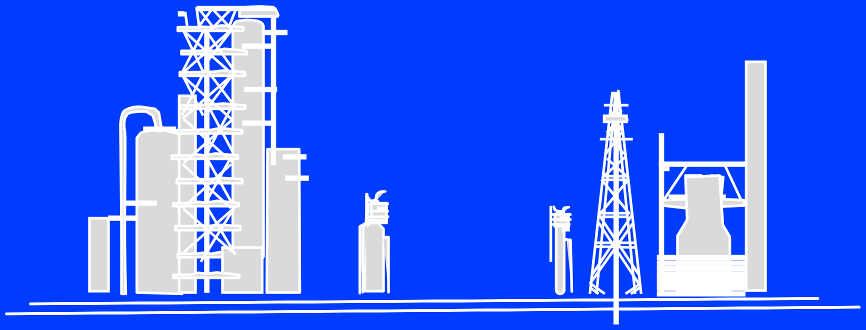
- Increased viscosity
- Deposit formation
- Bearing corrosion
- Increased acid number

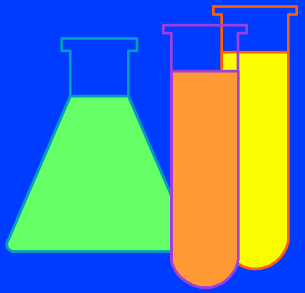


Oxidation Stability

Oxidation resistance of a lubricant depends on:

Base Oil Quality





Careful selection of Additives…………..

Oxidation Inhibitors

Functions:

Reduce lubricant oxidation

- Viscosity increase
- Acid
- Insolubles

Reduce varnish formation

- Caused by insolubles

Reduce Cu/Pb bearing corrosion

- Caused by acids

Oxidation Inhibitors

Types and Typical Compositions

Chain stopping (Radical Traps)

R• + **InH** → RH + **In•**

InH = inhibitor

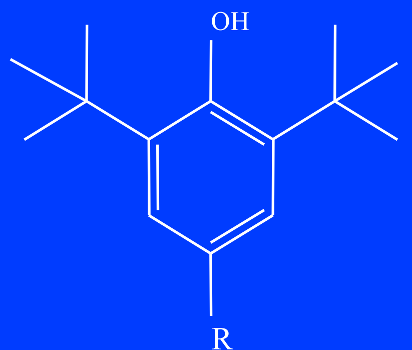
In• = **<u>low energy</u>** inhibitor radical

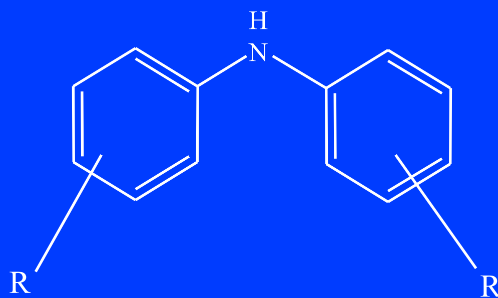
Hindered Phenols

Alkylated DiPhenyl Amines (DPA)

Salicylates

(Some) transition metals (Cu, Mo)





Peroxide Decomposers

ROOH + **InH** → RH + H_2O + **In**

- Zinc Dialkyl Dithiophosphate (ZDDP)
- (Some) sulphur compounds

Oxidation Stability

Engine constraints requiring an increased oxidation stability:

- Higher specific output power
- Lower capacity oil sumps
- Extended oil drain intervals
- Higher working temperatures

Lubricant Characteristics

- Viscosity
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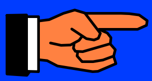
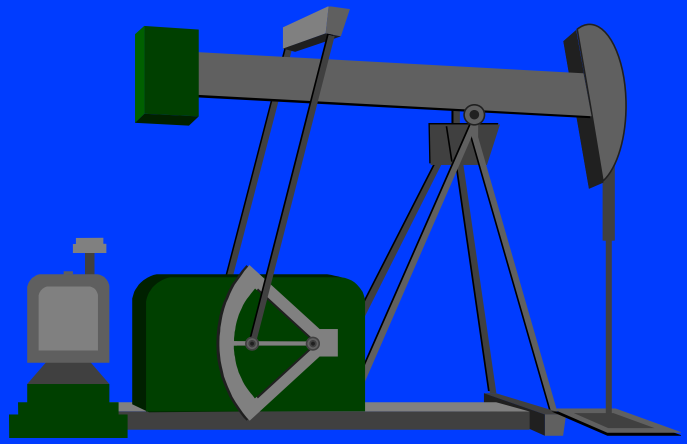
- Oxidation stability
-  Thermal stability
- Detergency
- Dispersancy
- Alkalinity
- Anti-Wear
- Anti-Rust and Anti-Corrosion
- Ash content

Thermal Stability

Resistance of a lubricant to decompose, under high operating temperatures.

Depends on the basestock used

Is not usually improved with additives



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Definition

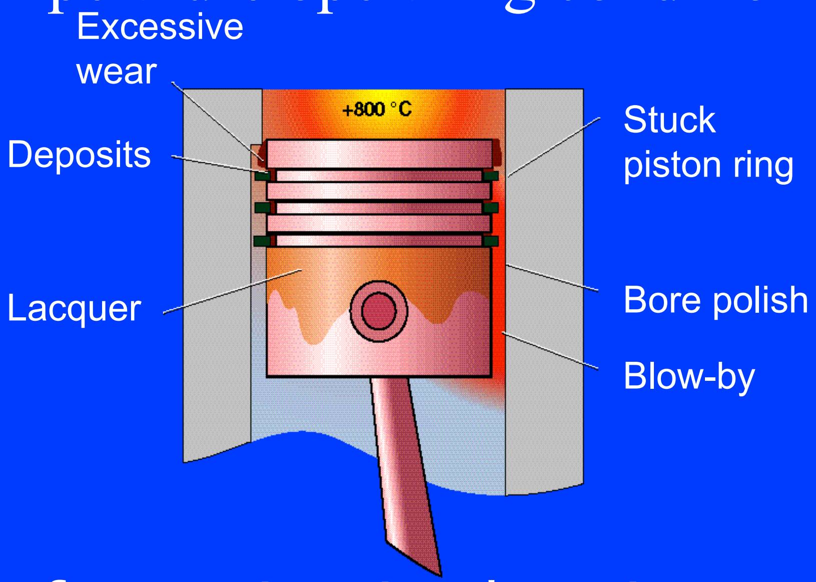
Property of a lubricant enabling it to neutralize the chemical substances that can lead to deposit formation on engine parts. These substances are formed by fuel combustion at high temperature or as a result of burning fuels with high sulfur content.

Metal Detergents

Neutralise acidic blow-by gases
  - prevent corrosive wear

Reduce lacquer, carbon and varnish deposits on pistons

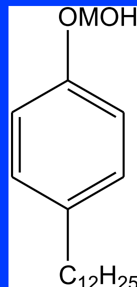
Prevent ring sticking under severe high-temperature operating conditions



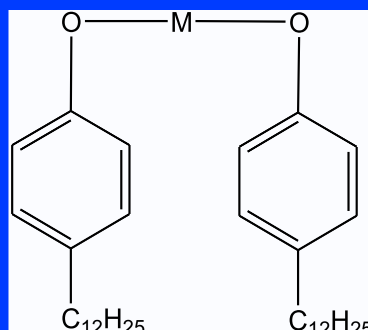
Deposit formation in the piston assembly

Typical additive compositions are ……….

Phenates

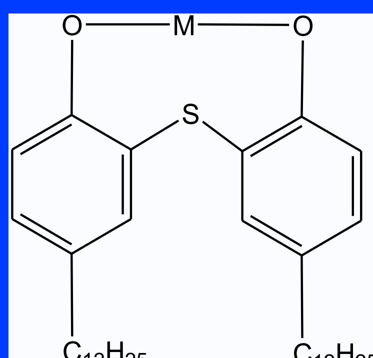


"Basic" Metal Phenate



+ Colloidal MCO_3

Overbased Metal Phenate



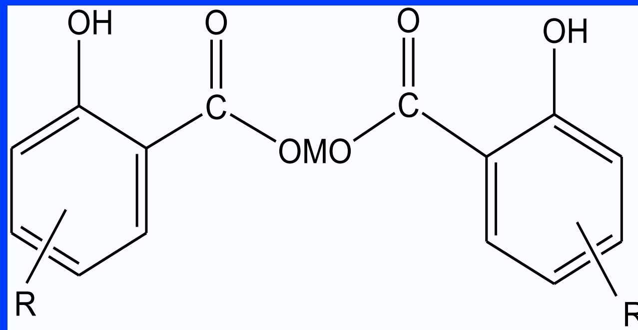
+ Colloidal MCO_3

Overbased Sulphurized Metal Phenate

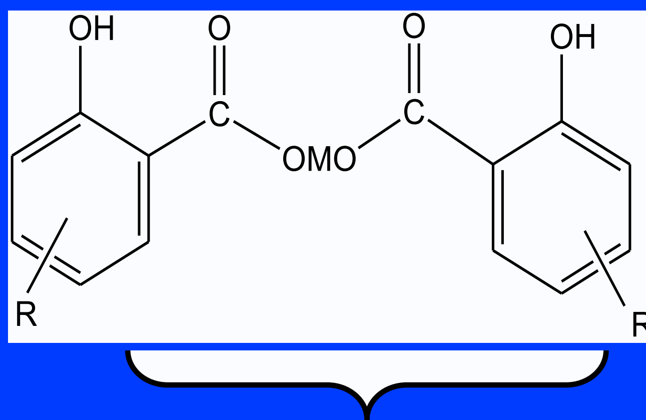
M = Calcium, Magnesium

R = Long non-polar "tail"

Salicylates



Neutral Metal Salicylate



Overbased Metal Salicylate

+

Colloidal MCO_3
+M(OH)2

“Soap”

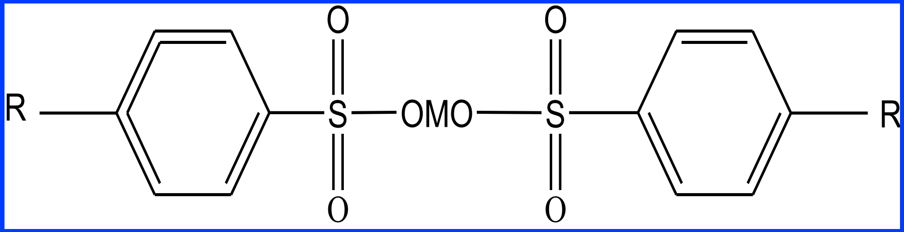
Carbonate “Core”

M = Calcium, Magnesium

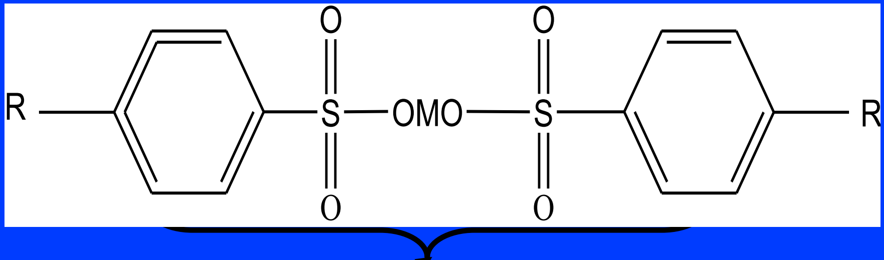
R = Long non-polar "tail"

Sulphonates

Neutral Metal Sulphonate



Overbased Metal Sulphonate



+

Colloidal MCO_3
+ M(OH)2

"Soap"

Carbonate "Core"

M = Calcium, Magnesium

R = Long non-polar "tail"

Lubricant Characteristics

- Viscosity
- Viscosity Index
- Low temperature fluidity
- Flash point
- Oxidation stability
- Thermal stability
- Detergency

- Dispersancy
- Alkalinity
- Anti-Wear
- Anti-Rust and Anti-Corrosion
- Ash content

Dispersancy

Dispersant Additives

These engine oil additives help prevent sludge, varnish and other deposits, avoiding carbonaceous residues joined together forming bigger deposits in engine parts.

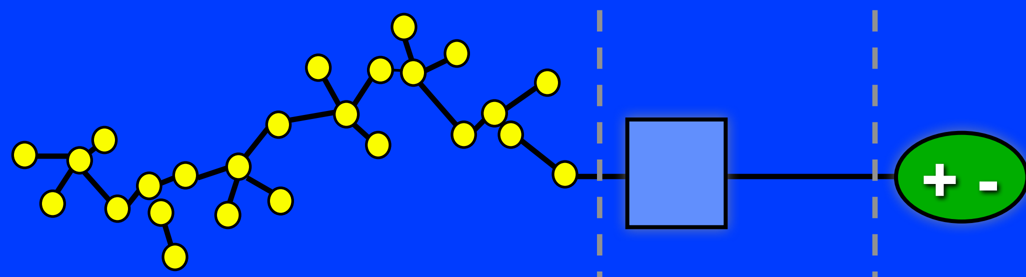
Usually they are non-metallic and generally used in combination with detergents.

Disperse sludge and varnish which have a strong adhesion to metallic surfaces and are very difficult to remove.

Keep things clean

- Engine oil is rubbish collector
- Engine oil is rubbish dump

Dispersants

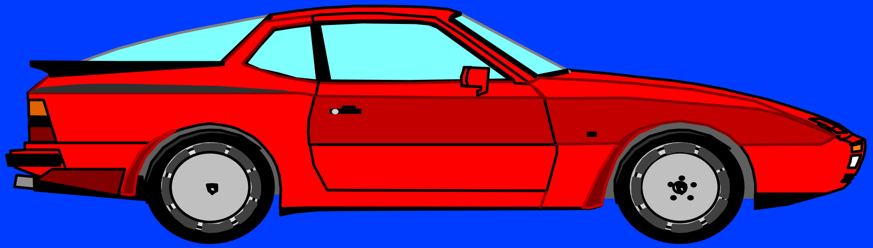


Oleophile (oil-loving)	Bridge	Polar head
Example PolyIsoButylene	Succinic Acid	Polyalkylene AMine

= **PIBSA/PAM**

Detergent Additives and Dispersant Additives

Reduce and delay engine deposit formation



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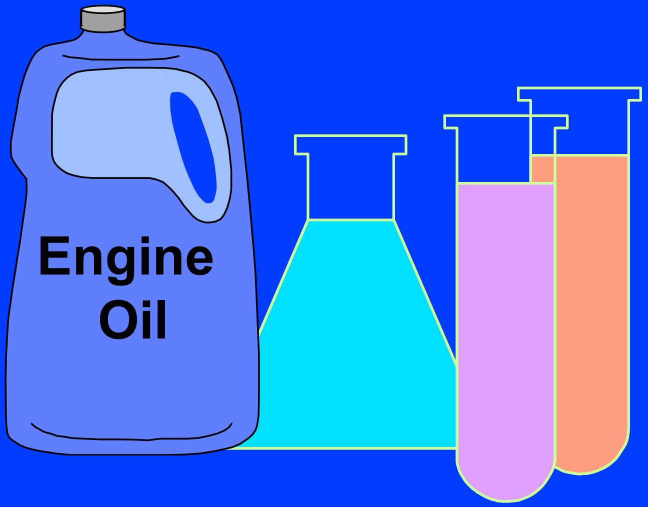
Alkalinity

Definition

Lubricant's ability to neutralize the acidic end products of fuel combustion and oil oxidation.



Alkalinity

Most detergent additives, and to a lesser extent many dispersant additives, have a significant basic characteristic.

The lubricant's content of alkaline components is given by TBN (Total Base Number).

The alkalinity reserve of an oil (TBN) is consumed during normal engine working service and is due to the neutralization of strong acids from fuel combustion.

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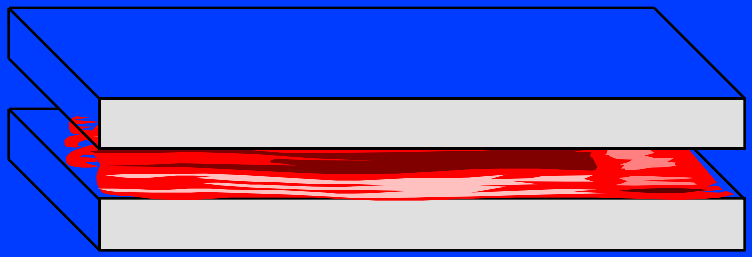
Anti-Wear

Definition

Lubricant's capacity to prevent or reduce wear on highly loaded parts when it is not possible to guarantee hydrodynamic lubrication conditions.



Anti-Wear Agents

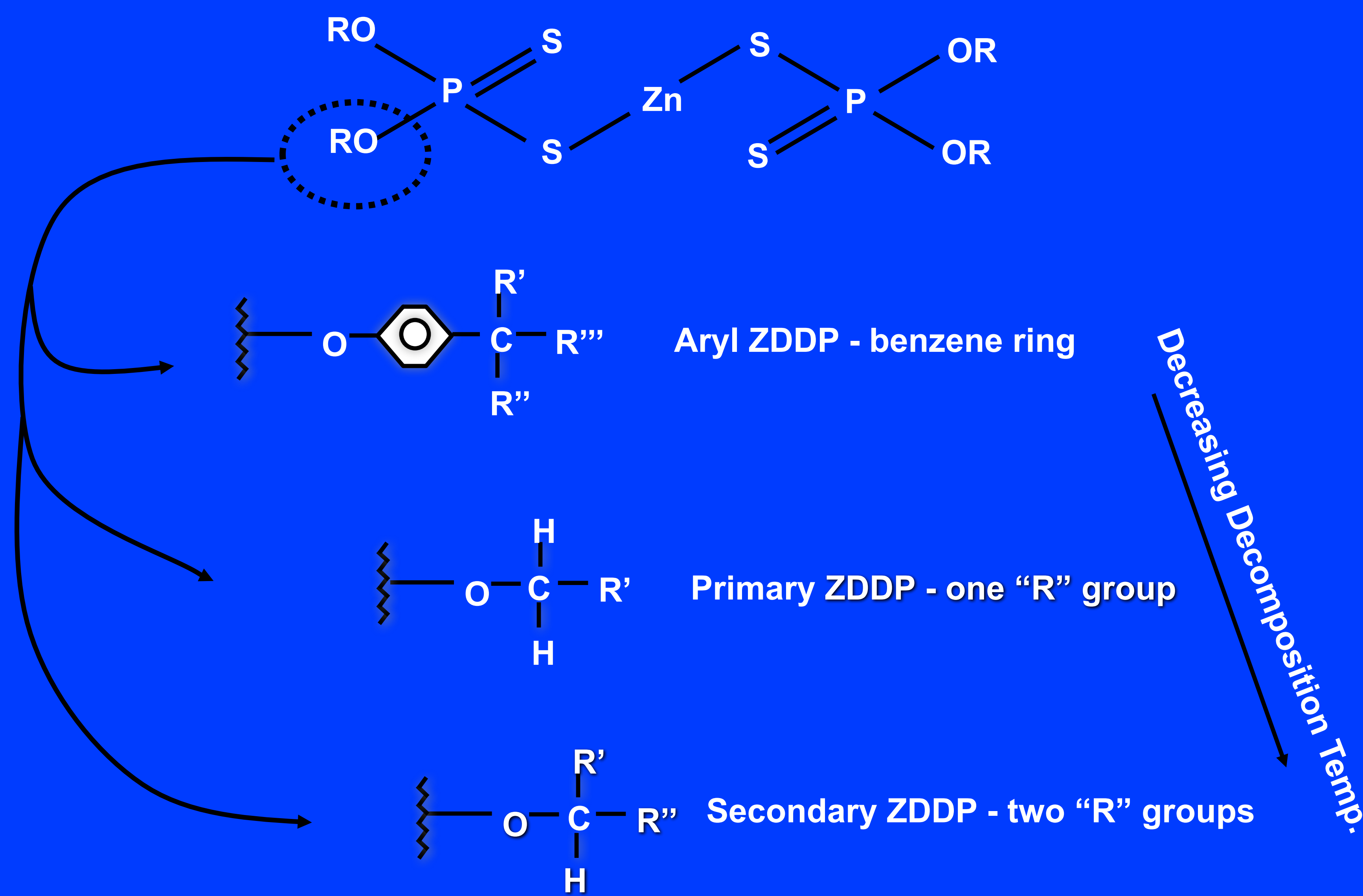
Function

- Reduce metal-metal wear

Types

- Zinc-containing
- Ashless phosphorus based (mainly ATF's)
- Extreme pressure
  - Gear oils

Zinc Dialkyl DithioPhosphate (ZDDP)



Lubricant Characteristics

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Anti-Rust and Anti-Corrosion

Causes

Rust:

Chemical attack of the metallic surfaces due to humidity and water condensation.

Effective additives for control of rust are Metal sulphonates, Ethoxylated phenol, Alkenyl succinic acid and Imidazoline derivatives

Corrosion:

Chemical attack of the surfaces by organic acids from fuel combustion, oxidation and contaminants.

Effective additives are Alkyl thiadiazoles

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Ash Content

Ash:

Metallic deposits formed in the combustion chamber and other engine parts, during high temperature operation.

High levels give:

- Combustion chamber deposits
- Ring wear

Due to their metallic composition, high contents of detergent additives in the oil leave a slight ash when the oil is burned. The dispersants, being non-metallic additives, do not contribute to ash level increase when the oil is burned.

Lubricant Characteristics Summary

Characteristics	Engine	Transmission Differential	Wet Brake/PTO Clutch	Hydraulics
High temp. viscosity	++	+	+	+
Low temp. Fluidity	+			++
Detergency/dispersancy	++			
Oxidation/thermal stability	++		+	++ +
Load carrying/anti-wear	+	++		+
Rust/corrosion prevention	+	+		
Water tolerance				++
Seal compatibility	+	+	+	+
Anti foam	+	+		+
Correct frictional req.			++	

Synthetic Lubricants

Synthetic lubricants are developed to greatly surpass the toughest requirements of the modern automotive and industrial equipment.

ExxonMobil is a pioneer in the development of Synthetic Lubricant technology, continuously developing and marketing synthetic products world-wide recognized as the market references.

Synthetic Lubricants

'Fluids made by chemically reacting materials of specific chemical composition to produce compounds with planned and predictable properties'

Synthetic lubricants are used with the following objectives:

✓ To protect the equipment in severe operating conditions

- Constant operation close to the design limits
- Demanding mechanical and thermal loads
- Adverse environmental conditions

✓ To optimize the use of the equipment

- Longer oil drain periods; less downtimes
- Lower maintenance costs

Synthetic Lubricants

Advantages

High viscosity index; adequate oil film maintained at all temperatures

Exceptional oxidation stability

Remarkable low temperature fluidity

Excellent levels of detergency and dispersancy

High chemical and thermal stability

Fuel economy benefits

Thank You