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

- Anti-Wear
- Cooling
- Cleanliness
- Sealing
- Anti-corrosion
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)
Striebeck curve and lubrication regions

[I] Boundary Lubricant

[II] Elastohydrodynamic lubricant region

[III] Hydrodynamic lubrication

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

Load

Moving Surface

Lubricant film

Static surface

Oil film thickness greater than surface microtexture
Relationship between Striebeck curve and friction modification

Friction coefficient

Hydrodynamic lubrication region

Region where friction modifiers are effective

Boundary Lubricant

Mixed lubricant region

Elastohydrodynamic lubricant region

Hydrodynamic lubrication region

Engine efficiency

Viscosity

(Velocity and load are kept constant)
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

\[ R = \text{C14 to C20 (saturated)} \]

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

Basestock 1

Additive 1

Additive 2

Additive 3

Additives n

Basestock 2

Finished Product
The Key is Balancing the Additives for the Application

Formulation Science

"The Oil"
Marine
ATF  PCMO
HD  2T  Gear
Oil

Dispersant
Detergent
FM
LOFI
VM
Basestock
Anti-oxidants
Anti-wear
Anti-rust
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.

<table>
<thead>
<tr>
<th>API Group</th>
<th>Sats, %</th>
<th>Sulfur, %</th>
<th>VI</th>
<th>Typical Manufacturing Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>&lt;90</td>
<td>&gt;0.03</td>
<td>80-119</td>
<td>Solvent Processing</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
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<td>80-119</td>
<td>Hydroprocessing</td>
</tr>
</tbody>
</table>
Group III

Mineral Oil Basestocks

**Obtained by various processes**

Severely hydrotreated mineral oils

- Saturation of almost all aromatics and olefins.

<table>
<thead>
<tr>
<th>API Group</th>
<th>Sats,%</th>
<th>Sulfur,%</th>
<th>VI</th>
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</tr>
</thead>
<tbody>
<tr>
<td>I</td>
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<td>80-119</td>
<td>Hydroprocessing</td>
</tr>
<tr>
<td>III</td>
<td>&gt;90</td>
<td>&lt;0.03</td>
<td>120+</td>
<td>Wax Isomerization, H.C, GTL</td>
</tr>
</tbody>
</table>
Group IV Polyalphaolefins (PAO) (SpectraSyn, SpectraSyn Plus, SpectraSyn Ultra)

<table>
<thead>
<tr>
<th>Synthetic</th>
<th>Mineral Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure compounds</td>
<td>Complex mixtures</td>
</tr>
<tr>
<td>(no wax or impurities)</td>
<td>Compromise among properties</td>
</tr>
<tr>
<td>Tailored properties</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
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<td>&lt;0.03</td>
<td>120+</td>
<td>Wax Isomerization, H.C, GTL</td>
</tr>
<tr>
<td>IV</td>
<td>n.a</td>
<td>n.a</td>
<td></td>
<td>Polyalphaolefins (PAO)</td>
</tr>
<tr>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td>All Other Basestocks</td>
</tr>
</tbody>
</table>

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
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- 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

Kinematic Viscosity (Log)

Temperature

Viscosity

$V_C \quad T_C$

$V_A \quad T_A$

$V_B \quad T_B$
Viscosity Units

✓ Viscosity Types

Kinematic: expressed in Stoke (St) or Centistoke (cSt)
(1 cSt = 0.01 St = 1 mm²/s)

Dynamic Viscosity = Density \times \text{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

<table>
<thead>
<tr>
<th>If Viscosity is too</th>
<th>May result in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Increased wear</td>
</tr>
<tr>
<td>Low</td>
<td>Increased oil consumption</td>
</tr>
<tr>
<td>Low</td>
<td>Increased oil leaks and noise</td>
</tr>
<tr>
<td>High</td>
<td>Increased operating temperature and reduced output power and poorer fuel economy</td>
</tr>
</tbody>
</table>

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

- Viscosity
- Viscosity Index
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Measures the change in viscosity of a fluid with a change in temperature

**Viscosity Index**

Lower Viscosity Index

Higher Viscosity Index

Temperature

Kinematic Viscosity (Log)
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

<table>
<thead>
<tr>
<th>SAE Viscosity Grade</th>
<th>Cranking (cP) max at temperature °C, measured in CCS</th>
<th>Pumping (cP) max. With no yield stress at temperature (°C)</th>
<th>Kinematic Viscosity (cSt) at 100 ºC</th>
<th>High Shear Rate (cP) @ 150 ºC min</th>
</tr>
</thead>
<tbody>
<tr>
<td>0W</td>
<td>6200 @-35 °C</td>
<td>60,000 @ -40 °C</td>
<td>3.8</td>
<td>-</td>
</tr>
<tr>
<td>5W</td>
<td>6600 @-30 °C</td>
<td>60,000 @ -35 °C</td>
<td>3.8</td>
<td>-</td>
</tr>
<tr>
<td>10W</td>
<td>7000 @-25 °C</td>
<td>60,000 @ -30 °C</td>
<td>4.1</td>
<td>-</td>
</tr>
<tr>
<td>15W</td>
<td>7000 @-20 °C</td>
<td>60,000 @ -25 °C</td>
<td>5.6</td>
<td>-</td>
</tr>
<tr>
<td>20W</td>
<td>9500 @-15 °C</td>
<td>60,000 @ -20 °C</td>
<td>5.6</td>
<td>-</td>
</tr>
<tr>
<td>25W</td>
<td>13,000 @-10 °C</td>
<td>60,000 @ -15 °C</td>
<td>9.3</td>
<td>-</td>
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<tr>
<td>20</td>
<td>-</td>
<td>-</td>
<td>5.6</td>
<td>&lt;9.3</td>
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<td>40(1)</td>
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<tr>
<td>50</td>
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<td>-</td>
<td>16.3</td>
<td>&lt;21.9</td>
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<tr>
<td>60</td>
<td>-</td>
<td>-</td>
<td>21.9</td>
<td>&lt;26.1</td>
</tr>
</tbody>
</table>

- (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

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

<table>
<thead>
<tr>
<th>ISO Viscosity Grade (ISO VG)</th>
<th>Kinematic Viscosity cSt @ 40°C (104°F)</th>
<th>Kinematic Viscosity Limit cSt @40°C (104°F)</th>
<th>Kinematic Viscosity Limit cSt @40°C (104°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>midpoint</td>
<td>minimum</td>
<td>maximum</td>
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<tr>
<td>2</td>
<td>2.2</td>
<td>1.98</td>
<td>2.42</td>
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<td>3.2</td>
<td>2.88</td>
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<td>4.6</td>
<td>4.14</td>
<td>5.06</td>
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<td>6.12</td>
<td>7.48</td>
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<td>11.0</td>
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<td>680</td>
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<td>1100</td>
</tr>
<tr>
<td>1500</td>
<td>1500</td>
<td>1350</td>
<td>1650</td>
</tr>
<tr>
<td>2200</td>
<td>2200</td>
<td>1980</td>
<td>2420</td>
</tr>
<tr>
<td>3200</td>
<td>3200</td>
<td>2880</td>
<td>3520</td>
</tr>
</tbody>
</table>

1 cSt = 1 mm²/s
Lubricant Characteristics

- Viscosity
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- Low temperature fluidity
- Flash point
- Oxidation stability
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- Detergency
- Dispersancy
- Alkalinity
- Anti-Wear
- Anti-Rust and Anti-Corrosion
- Ash content
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.
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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)
\[ R\cdot + \text{InH} \rightarrow RH + \text{In}\cdot \]
\[ \text{InH} = \text{inhibitor} \]
\[ \text{In}\cdot = \text{low energy} \text{ inhibitor radical} \]

Hindered Phenols
Alkylated DiPhenyl Amines (DPA)
Salicylates
(Some) transition metals (Cu, Mo)

Peroxide Decomposers
\[ \text{ROOH} + \text{InH} \rightarrow RH + H_2O + \text{In} \]
- 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

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Thermal Stability

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

Depends on the basestock used

Is not usually improved with additives
Lubricant Characteristics

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Detergency

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

Overbased Metal Phenate

Overbased Sulphurized Metal Phenate

M = Calcium, Magnesium

R = Long non-polar “tail”
Salicylates

Neutral Metal Salicylate

Overbased Metal Salicylate

M = Calcium, Magnesium
R = Long non-polar "tail"

"Soap"

Carbonate "Core"

Colloida I
MCO₃ + M(OH)₂
Sulphonates

Neutral Metal Sulphonate

Overbased Metal Sulphonate

“Soap”

M = Calcium, Magnesium
R = Long non-polar "tail"

Carbonate “Core”

\[ \text{MCO}_3 + \text{M(OH)2} \]

Overbased Metal Sulphonate:

\[
\text{R-S-O-M-S-O-R} + \text{M(OH)2} \rightarrow \text{R-S-O-M-S-O-R} + \text{MCO}_3
\]
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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)

Example Polyisobutylene

Bridge

Succinic Acid

Polyalkylene Amine

= PIBSA/PAM
Detergency & Dispersancy

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)

- Primary ZDDP - one “R” group
  \[ \text{O} \text{C} \text{R}’ \text{H} \]

- Secondary ZDDP - two “R” groups
  \[ \text{O} \text{C} \text{R}’ \text{H} \]

- Aryl ZDDP - benzene ring
  \[ \text{O} \text{C} \text{R}’ \text{R}’’ \text{R}’’’ \]

- Decreasing Decomposition Temp.
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
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
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
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

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