Introduction

Base stocks are the main component in lubricants.

Base stocks exhibit certain properties that impact how the lubricant performs in the engine:

- Base stocks are not all the same and these properties can vary enormously from base stock to base stock.
- Important when designing lubricant formulations but not always easy to understand and interpret.

Additives are used to enhance the performance of the base stock and to impart additional beneficial properties onto the lubricant.

Performance you can rely on.
Why are Base Stocks Important?

Base stocks can have a major effect on **performance**.

Some of these effects can be overcome by **additive selection**.

- Sludge
- Oxidation
- Wear Protection
- Soot Handling
- Deposits
- Fuel Economy
- Low Temperature Pumpability
- Volatility

Why are Base Stocks Important?

Base stocks can have a major effect on **performance**.

Some of these effects can be overcome by **additive selection**.
# Basic Chemistry of Base Stocks

<table>
<thead>
<tr>
<th>Type</th>
<th>Example Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Saturates</strong></td>
<td></td>
</tr>
<tr>
<td>Paraffinic Straight Chain</td>
<td><img src="image1" alt="Structure" /></td>
</tr>
<tr>
<td>Paraffinic Branched Chain</td>
<td><img src="image2" alt="Structure" /></td>
</tr>
<tr>
<td>Naphthenic</td>
<td><img src="image3" alt="Structure" /></td>
</tr>
<tr>
<td><strong>Unsaturates</strong></td>
<td></td>
</tr>
<tr>
<td>Olefin</td>
<td><img src="image4" alt="Structure" /></td>
</tr>
<tr>
<td>Aromatic</td>
<td><img src="image5" alt="Structure" /></td>
</tr>
<tr>
<td><strong>Polar Constituents</strong></td>
<td></td>
</tr>
<tr>
<td>Sulphur Containing</td>
<td><img src="image6" alt="Structure" /></td>
</tr>
<tr>
<td>Nitrogen Containing</td>
<td><img src="image7" alt="Structure" /></td>
</tr>
</tbody>
</table>
Properties of Base Stocks
# Viscosity

<table>
<thead>
<tr>
<th>Shear</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Cranking Simulator (CCS)</td>
<td>High Temperature High Shear (HTHS)</td>
</tr>
<tr>
<td>Pumpability via Mini Rotary Viscometer (MRV)</td>
<td>Kinematic Viscosity (kV)</td>
</tr>
</tbody>
</table>

Dependent upon **distillation conditions**

Different measures depending on **temperature** and **amount of shear**

**IMPACT ON ENGINE PERFORMANCE:**
- Fuel economy
- Wear
Viscosity Index (VI)

**Base stocks become thinner** with increasing temperature

The higher the VI the **less the base stock thins**

**Flexible molecules** have high VI

- Change configuration with temperature

At low T

Flexible molecules have high VI

- Change configuration with temperature

At high T
NOACK Volatility

Measures **evaporation loss**

Dependent on small molecule content of the base stock ("light ends")

Wider distribution means there are more small molecules and higher volatility

**IMPACT ON ENGINE PERFORMANCE:**

- Oil consumption
- Deposits

Base Stock A
Base Stock B
Base Stock C

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Pour Point

Defined as **temperature at which base stock becomes semi-solid and loses its flow characteristics**

- Related to melting point
- Effect is seen in low temperature crystallisation

Depends on level of rings and branching relative to straight chain paraffins; base stocks with high levels of rings and branching tend to have lower pour points
Saturates

Dependent on processing conditions

Level of saturates impacts:

- Susceptibility of the base stock to undergo oxidation
- Solvency and additive compatibility
Sulphur and Nitrogen Content

Dependent upon **processing conditions**

**Sulphur** is a natural **antioxidant**

**Nitrogen** is a natural **pro-oxidant**

IMPACT ON ENGINE PERFORMANCE:
- Oxidation and viscosity increase
Base Stock Classification
# API Base Stock Classification

Base stocks are classified according to their properties, and the saturate and sulphur content.

<table>
<thead>
<tr>
<th>Group</th>
<th>Viscosity Index</th>
<th>Saturates</th>
<th>Sulphur</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>$80 \leq x &lt; 120$</td>
<td>&lt; 90%</td>
<td>and/or</td>
<td>&gt; 0.03%</td>
</tr>
<tr>
<td>II</td>
<td>$80 \leq x &lt; 120$</td>
<td>≥ 90%</td>
<td>and</td>
<td>≤ 0.03%</td>
</tr>
<tr>
<td>III</td>
<td>≥ 120</td>
<td>≥ 90%</td>
<td>and</td>
<td>≤ 0.03%</td>
</tr>
<tr>
<td>IV</td>
<td></td>
<td></td>
<td></td>
<td>PAO (Poly Alpha Olefins)</td>
</tr>
<tr>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td>Everything Else</td>
</tr>
</tbody>
</table>
Group II+ and Group III+ Base Stocks

Each of the API base stock groups cover a broad range of properties

Different base stocks within the same group can have very different properties

The terms Group II+ and Group III+ describe base stocks with a viscosity index that is higher in the range for their group

• This is a marketing term with no formal definition

Generally

For Group II+ base stocks: \( \text{VI} > 110 \)
For Group III+ base stocks: \( \text{VI} > 130 \)
# Comparison of Base Stock Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Saturates</th>
<th>Sulphur Content</th>
<th>Volatility</th>
<th>Oxidative Stability</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Variable</td>
<td>Low</td>
</tr>
<tr>
<td>II</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>III*</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>IV</td>
<td>Very High</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Very High</td>
<td>High</td>
</tr>
<tr>
<td>V**</td>
<td>Very High</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Variable</td>
<td>High</td>
</tr>
</tbody>
</table>

* Includes GTL
** Polyol ester used to improve polarity

Performance you can rely on.
Base Stock Selection

When selecting a base stock for a formulation, the properties and cost of the base stock need to be considered.

- Better high temperature viscometrics without low temperature viscosity increase

Base stocks will be selected in order to meet **viscometric and volatility requirements**.

- Thinner oils can be blended whilst maintaining volatility.
Refinery Overview

Crude oil → Refinery processes → Petroleum products
Crude Selection

Each crude source has a different composition

- Hydrocarbons
- Sulphur compounds
- Nitrogen compounds
- Others

Availability of various crudes

Determined by economics

- Supply vs. demand
- Fuel economics may be overriding

Political considerations may be important
Refining Process

Crude Oil

Vacuum Distillation

- Solvent Extraction
- Solvent Dewaxing
- Hydro-finishing
  - Group I Base stocks

Hydro-cracking

- Catalytic Dewaxing
- Hydro-finishing
  - Distillation
  - Group II Base stocks

Hydro-isomerisation

- Catalytic Dewaxing
- Hydro-finishing
  - Distillation
  - Group III Base stocks

Performance you can rely on.

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Vacuum Distillation

Distillation:

- Separates lighter from heavier fractions
- Selects viscosity “cut”
- Controls volatility (evaporation)
Solvent Extraction

**Separation** based on solubility

**Uses a polar solvent** to remove less desirable molecules

- Aromatics

**The more desirable molecules remain in the oil**

- Straight and branched chain paraffins
- Naphthenes
Refining Process

Vacuum Distillation

Crude Oil

Solvent Extraction

Solvent Dewaxing

Hydro-finishing

Group I Base stocks

Hydro-cracking

Catalytic Dewaxing

Hydro-finishing

Distillation

Group II Base stocks

Hydro-isomerisation

Catalytic Dewaxing

Hydro-finishing

Distillation

Group III Base stocks
Solvent Dewaxing and Hydrofinishing

Solvent Dewaxing

Reduces the pour point and viscosity index of the base oil by removing wax

Separation is based on solubility

Wax is less soluble in solvent than oil

- Oil and solvent mixture is chilled
- Wax is filtered out at low temperature

Hydrofinishing

Improves colour stability and acidity of the base oil

- Sulphur, nitrogen, oxygen removed as H₂S, NH₃ and H₂O
- Slight hydrogenation of unsaturated compounds

Oil is contacted with hydrogen at about 600 psi and 250 – 320°C
Hydrocracking

Conversion of unsaturated and aromatic molecules which are less desirable into more desirable saturated chains

‘Cracking’ means breaking apart

‘Hydro’ means adding hydrogen

‘Hydrocracking’ is breaking bonds and adding hydrogen

- Hydrocracking usually implies high severity
- Hydrofinishing usually implies low severity
- Hydrotreatment can mean either
Refining Process

Crude Oil

Vacuum Distillation

- Solvent Extraction
  - Solvent Dewaxing
    - Hydro-finishing
      - Group I Base stocks

- Hydro-cracking
  - Catalytic Dewaxing
    - Hydro-finishing
      - Distillation
        - Group II Base stocks

- Hydro-isomerisation
  - Catalytic Dewaxing
    - Hydro-finishing
      - Distillation
        - Group III Base stocks
Hydroisomerisation

Rearrangement of linear chains to branched chains
- I.e. transforming wax to iso-paraffins

Improves the VI of a base stock

The process varies for each manufacturer and therefore the properties of Group III base stocks can also be quite different.
Refining Process

Crude Oil

Vacuum Distillation

Hydro-cracking

Dewaxing

Hydro-finishing

Group I
Base stocks

Solvant Extraction

Solvent Extraction

Dewaxing

Hydro-finishing

Hydrofinishing

Group II
Base stocks

Hydro-

isomerisation

Catalytic

Dewaxing

Catalytic

Dewaxing

Hydro-finishing

Distillation

Hydro-

finishing

Group III
Base stocks

Distillation

Crude Oil

Refining Process
Synthetic Base Stocks
Synthetic Base Stocks

Group I, Group II and Group III base stocks that are manufactured by refining processes are referred to as ‘mineral’ base stocks.

The term ‘synthetic’ is used to describe lubricants that have been processed:

- This includes Group IV base stocks.

‘Synthetic’ is also used when marketing Group III base stocks that have been severely hydrocracked.

‘Semi-synthetic’ is a marketing term that does not necessarily reflect base stock quality.
Gas to Liquids (GTL)

Processed from natural gas

Performance comparable to Group III / IV base stocks:

- High VI (140+)
- Low Noack volatility
- Low pour point
- Stable
- High Saturates
- No Sulphur or Nitrogen

Classed as Group III by API definition

- But it would be a “synthetic base oil” in all markets!

First used by Shell from 1994

Other oil companies now investing in GTL production

Large initial investment but production cost comparable to Group II
Refinery Process for GTL

GTL produced by reacting the low molecular weight materials found in natural gas to form higher molecular weight materials.

Natural Gas → Fischer-Tropsch Process → Hydrocracking / Hydroisomerisation → GTL

Makes normal paraffins

Obtain desired molecular weight and structure

Process is well controlled and can be adjusted to make different molecular structures with predictable properties.
Synthetic Process - PAO

Poly alpha-olefins (PAO) are manufactured **from** linear alpha olefins (typically 1-decene)

They have a branched paraffinic structure leading to desirable properties
- High VI, low NOACK, good oxidative stability

The process is very controlled **leading to** narrow properties

Double bond (olefin)
An alpha olefin

Poly alpha-olefin PAO
Group V Base Stocks

**Group V** defined as ‘Everything else’ not classified in the other API groups

Examples of Group V base stocks

**Di-Esters**
Industrial applications are highest growth
Competitive with PAO in performance attributes

**Polyol Esters**
High-temperature applications
More costly than PAO, di-esters

**Phosphoric Acid Esters**
Used in fire resistant fluids

**Silicone Oils**
Used as heat transfer oils

Versatile, custom made for specialised applications
Re-refining

Used motor oil → Low pressure hydroprocessing → Re-refined base oil

Used additives/contaminants

Processing very similar to conventional processes
- Solvent extraction
- Hydrocracking

Quality depends on
- Starting material
- Processes
- Desired targets

Possible to make Group I and Group II base stocks with re-refining

Just like conventional base stocks!
Drivers and Market Trends
Many of main drivers for lubricant performance result is driven by need for improved base stock quality

- Improved Base Stock Quality
- Fuel economy
- Extended ODIs
- Aftertreatment compatibility
- Marketing advantage
Trend in Base Stock Demand

- Decline in demand for Group I base stocks
- Increase in demand for higher quality Group II and Group III base stocks

Chart Source: Global Lubricants Basestocks: Market Analysis and Opportunities, Kline & Company. Note: Demand estimates include only Group I, II/II+, III/III+ and PAO basestocks and exclude Group V basestocks.
Trends in Group III Base Stocks

- Increase in Group III capacity from 2011 – 2017
- Largest proportion of Group III production in Asia and Europe / Middle East
- Potential for further investment in USA and Russia
Trends in Group IV Base Stocks

- The PAO market is < 2% of total base stock market
- Main production capacity in US and Europe
- Global demand in PAO is increasing
- Increased capacity in PAO and LAO raw materials have been announced
Summary

Base stocks are the main component in lubricants
Have a significant effect on performance

Base stocks are complex mixtures of molecules
Derived from crude oil by refinery processes

Physical properties are also important
Viscosity, Viscosity Index, pour point, volatility

Performance testing of products still required
- Compositional effects not well enough known
- Additives are a major factor in finished products

General trend is move towards better quality base stocks
- Drive for fuel economy
- Move from Group I to higher quality base stocks

Chemical composition determines performance
Saturates and sulphur usually most important, but not the whole story
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