Lubricant base stocks

Outline

• What are base stocks?
  – Why are base stock important?
  – Composition of base stocks
• Refining processes
  – Overview
  – Major base stock types
    • Solvent Extraction (SE)
    • Hydrocracking (HC)
    • Synthetics
    • Others
• API base oil groups
• Names and definitions
• Measurements and typical targets
• Recent trends
Lubricant base stocks

- A lubricant component
  - Roughly 80-99+% of petroleum products
  - Usually doesn’t have all required properties – needs additive enhancement
- Mineral oil base stocks
  - Refined from crude oil
  - Petroleum = “Petra-oleum” = “Rock Oil”
  - Common processes
    - Solvent extraction
      - Separate “good” from “bad” molecules
    - Hydrocracking
      - Convert “bad” molecules into “good” molecules
    - Synthesis
      - “Built” from chemical reactions
- Animal and vegetable oils also used

Why are base stocks important?

1. They are the major component in lubricants
2. They have a major effect on performance (oxidation)

- Gasoline Engine Oxidation Test
- Same PCEO Additive System in different base stocks

3. They have a major effect on performance (soot-handling)

- Diesel Engine Soot Test (retarded timing for NOx control)
- Same HDDO Additive System in different base stocks
Lubricant properties affected by base stocks

- Viscometrics
  - SAE viscosity grade (e.g., SAE 5W-30)
  - Pour point and low temperature fluidity
  - Fuel economy
  - Wear protection
- Oxidation
  - Viscosity increase
  - Acid formation, that leads to corrosion
  - Deposit control
- Dispersancy and solvency
  - Soot control (HDD)
  - Viscosity increase and filter plugging
  - Sludge
  - Deposit control
- Foaming and air entrainment
- Volatility (evaporation)
  - Oil Consumption and Flash Point

What are base stocks?

- Base stocks are primarily hydrocarbons
  - Hydrocarbon = molecule containing hydrogen and carbon
  - Sometimes generalized to molecules with other elements
- Equivalent chemical symbols:

\[ \text{C}_5\text{H}_{12} = \begin{array}{c}
  \text{H} \\
  \text{H} \\
  \text{H} \\
  \text{H} \\
  \text{H} \\
\end{array} \]

(3,3-Dimethylpentane)
Chemical bonds and terminology

• Carbon likes to have four bonds
  – In three dimensions

• Carbon can form chains (straight or branched)
  – Hydrogen fills in the remaining four spaces
    • All positions filled → relatively unreactive
    • Saturated (paraffin)

• If there’s a missing place, a double bond forms
  – Prefer to fill the spaces → more reactive; e.g., oxidation
    • Unsaturated = missing spaces

• Ring structures (saturated)
  – Six-membered rings are common, but others are possible
    • Naphthene (cyclo-alkanes)

• Six-membered rings with three double bonds
  – Lots of empty space → reactive
    • Aromatic

Base stock molecules – hydrocarbons

<table>
<thead>
<tr>
<th>Type</th>
<th>Structure</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paraffins</td>
<td></td>
<td>Very high VI (~175)</td>
</tr>
<tr>
<td>(no rings)</td>
<td></td>
<td>Excellent oxidation</td>
</tr>
<tr>
<td>Straight chain</td>
<td></td>
<td>Very high pour point</td>
</tr>
<tr>
<td>Branched chain</td>
<td></td>
<td>High VI (~100-150)</td>
</tr>
<tr>
<td>Naphthenes</td>
<td></td>
<td>Medium VI (~60-110)</td>
</tr>
<tr>
<td>(saturated rings)</td>
<td></td>
<td>Poor oxidation</td>
</tr>
<tr>
<td>Aromatics</td>
<td></td>
<td>Low VI (&lt;60)</td>
</tr>
<tr>
<td>(unsaturated rings)</td>
<td></td>
<td>Very poor oxidation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low pour point</td>
</tr>
</tbody>
</table>
### Base stock molecules – polars

<table>
<thead>
<tr>
<th>Type</th>
<th>Structure</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sulfur</strong></td>
<td><img src="image1.png" alt="Structure" /></td>
<td>Antioxidant</td>
</tr>
<tr>
<td>Dibenzothiophene</td>
<td><img src="image2.png" alt="Structure" /></td>
<td>Corrosive</td>
</tr>
<tr>
<td>Dialkylsulfide</td>
<td><img src="image3.png" alt="Structure" /></td>
<td></td>
</tr>
<tr>
<td><strong>Nitrogen</strong></td>
<td><img src="image4.png" alt="Structure" /></td>
<td>Mild pro-oxidant</td>
</tr>
<tr>
<td>Alkylhydrocarbazole</td>
<td><img src="image5.png" alt="Structure" /></td>
<td></td>
</tr>
<tr>
<td><strong>Oxygen</strong></td>
<td><img src="image6.png" alt="Structure" /></td>
<td>Usually not in base stock (formed during oxidation)</td>
</tr>
<tr>
<td>β-naphthenoic acid</td>
<td><img src="image7.png" alt="Structure" /></td>
<td></td>
</tr>
</tbody>
</table>
Refinery overview

Crude oil → Refinery processes → Petroleum products

Crude oil

- Crude oil is a mixture of thousands of different molecules
  - Some are GOOD for lubricants – some are BAD for lubricants
- Various classifications
  - “Light” vs. “Heavy”
  - “Sweet” vs. Sour”
  - Paraffinic vs. Naphthenic vs. Aromatic

<table>
<thead>
<tr>
<th>Light</th>
<th>Sweet</th>
<th>Sour</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Texas Intermediate (WTI)</td>
<td>Light-Sour Blend (Canada)</td>
<td></td>
</tr>
<tr>
<td>Brent (North Sea)</td>
<td>Arabian Extra Light</td>
<td></td>
</tr>
<tr>
<td>Heavy</td>
<td>Cano Limon (Colombia) Minas (Indonesia)</td>
<td>Maya Heavy (Mexico) Merey (Venezuela)</td>
</tr>
</tbody>
</table>

Sources: Shell; Stratas Advisors; Sanford C. Bernstein
Refining in a nutshell

- **Start**
  - Crude oil
  - Mixtures of **GOOD** and **BAD** molecules
- **Goal**
  - **REDUCE** the Proportion of **BAD** molecules
  - **INCREASE** the Proportion of **GOOD** molecules
- **How Do They Do That?**
  - Refining
  - Separation
    - Remove the **BAD** molecules
      - Throw them away?
      - Use them for something else!
    - Conversion
      - Change **BAD** molecules into **GOOD** molecules
  - Synthesis
    - Build **GOOD** molecules from small ones

Base stock refinery process overview

- **De-salting**
  - To avoid corrosion in refinery units
- **Distillation**
  - Separates lighter from heavier fractions
  - Selects viscosity “cut” and controls volatility (evaporation)
  - Also used at end as a “clean-up” step
- **Major Base Stock Refining Process**
  - **Solvent Extraction**
  - **Hydrocracking**
- **De-asphalting**
  - Removes asphaltenes (heavy aromatics)
- **Dewaxing**
  - Removes wax and improves low temperature properties
  - Either solvent dewaxing or catalytic dewaxing or catalytic iso-dewaxing
- Processes are combined to create refinery ‘schemes’ ➔
  - Optimized based on crude source and refinery assets
Major base stock refinery processes

- Distillation
  - Separates lighter from heavier fractions
  - Selects viscosity ‘cut’
  - Controls volatility (evaporation)

Gases
Crude Oil
Heavy Bottoms

U.S. refinery yields

- Gasoline 36%
- Distillate 31%
- Residual 14%
- Jet Fuel 12%
- Asphalts 5%
- Gases 8%
- Residual 3%
- Chemical Feedstocks 2%
- Wax 0.1%
- Base Stocks 1.1%

83% liquid fuels

Energy Information Agency,
U.S. Department of Energy
Major base stock refinery processes

- **Solvent Extraction** (Group I)
  - Separation technology
  - Polar solvent removes aromatics leaving good saturated molecules
  - Removes sulfur, which is predominantly in aromatic molecules

- **Hydrocracking** (Group II & III)
  - Conversion technology
  - Breaks chemical bonds and adds hydrogen
  - Increases saturates by adding hydrogen
  - Removes sulfur, converting to volatile H₂S
  - Group II vs III is a function of feedstock and hydrocracker severity

- **Synthesis** (Group III, IV, & V)
  - GTL – Gas to Liquid – combine methane (natural gas) into large hydrocarbons
  - PAO – PolyAlphaOlefin – combine small double-bond molecules
  - Esters – Build up specific molecules using various starting molecules

Solvent extraction refinery process
Hydrocracking refinery process

Solvent extraction

- Separation based on solubility
  - “Good” molecules are less polar
    - Straight and branched chain paraffins
    - Naphthenes
  - “Bad” molecules are more polar
    - Aromatics
- Use a polar solvent
  - “Bad” polar molecules end up in polar solvent
  - “Good” non-polar molecules stay in oil
- Must choose crudes with significant “good” molecules
Hydrocracking

- Conversion of “bad” molecules into “good” molecules
  - “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

![Chemical structure](image1)

Synthetic process – PAO

- Select small molecules from other refinery streams
- Build up good molecules from the small ones

![Chemical structure](image2)
Synthetic process – GTL*

- GTL = Gas-to-Liquids
  - Process of turning natural gas into liquid hydrocarbons
  - Primary focus is liquid fuel production, but base stocks can also be made
- Steam-Methane Reforming (SMR) to make "syngas"
  - Also other ways to make syngas
    \[
    \begin{align*}
    CH_4 + H_2O &\rightarrow CO + 3H_2 \\
    CO + H_2O &\rightarrow CO_2 + H_2 \\
    CH_4 + CO_2 &\rightarrow 2CO + 2H_2 \\
    \end{align*}
    \]
  - Net Reaction: \( CH_4 + H_2O \rightarrow 2CO + 3H_2 \)
  - "Syngas"
- Followed by Fischer-Tropsch synthesis
  \[
  nCO + (2n+1)H_2 \rightarrow C_nH_{2n+2} + nH_2O \]
- GTL base stocks have:
  - Very high saturates and Viscosity Index
  - Essentially no sulfur, nitrogen, aromatics, or olefins
- GTL's meet the chemical and physical definition of API Group III
- A few GTL plants started-up recently
  - A large fuels plant could become largest source of base stock

*"Chemistry and Technology of Lubricants," 3rd ed., Mortier, Fox, and Orszulik (Eds.), Springer, 2010

Gas-to-liquids

Source: RPS Energy, Lubes 'n' Greases, May 2014
Other base stock types (reference)

- Esters
  - Diesters
  - Polyol esters
  - Phosphate esters
- PolyAlkylene Glycol (PAG)
- Alkylated naphthene (AN)
- Polyphenyl ether
- Silicones
- Bio-based
  - Natural oils
  - Chemically-functionalized vegetable oils
  - Biotechnology renewable oils (e.g., from plant sugars via algae)
- Many others

Ref: "Synthetics, Mineral Oils, and Bio-Based Lubricants, Chemistry and Technology" L. R. Rudnick (ed.), CRC Taylor and Francis, 2006
Key base stock properties – overview

- **Viscosity** (D445)
  - Sometimes kinematic viscosity at 100°C
    - Examples: HC4, HC6, HC12
  - Sometimes “Neutral Number” – approx. 4.6 times kinematic viscosity at 40°C
    - Examples: S100N, S150N, S600N
  - ISO Grade for Industrial Oils – related to kinematic viscosity (mm²/s) at 40°C
- **Viscosity Index** (D2270)
  - Rate of change of viscosity with temperature
- **Low temperature properties**
  - CCS (D5293), MRV (D4684), SBV (D5133), or Pour point (D97)
- **Saturates** (D2007)
  - Measure of “stable” vs. “reactive” molecules
  - Intended as an approximation of oxidative stability – Not perfect
- **Sulfur** (D4294)
  - Corrosive and poison to exhaust catalysts
- **Vollatility** (D5800)
  - Evaporation
- **Chemical properties are also very important**

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API base oil classification
Base oil classification

- American Petroleum Institute (API)
  - Trade association of oil companies
- Wanted a way to classify base oils
  - Base oil is a mixture of (one or more) base stocks
- Intended for Base Oil Interchange Guidelines (BOIG)
  - To approve an additive package previously approved in another base oil
    - Using Read-Across
    - More detail in the Specifications and Passenger Car sections
- Now used for marketing, lobbying, and other commercial activities

API base oil classification

<table>
<thead>
<tr>
<th>Group</th>
<th>Vis. Index</th>
<th>Saturates</th>
<th>Sulfur</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>80 ≤ x &lt;120</td>
<td>&lt;90% and / or</td>
<td>&gt;0.03%</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>80 ≤ x &lt;120</td>
<td>≥90%</td>
<td>and</td>
<td>≤0.03%</td>
</tr>
<tr>
<td>II Plus</td>
<td>&gt;about 110</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>III Plus</td>
<td>&gt;about 135</td>
<td></td>
<td></td>
<td></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>
<tr>
<td>VI</td>
<td></td>
<td>Europe Only (ATIEL)</td>
<td></td>
<td>PIO (Poly Internal Olefins)</td>
</tr>
</tbody>
</table>

- Companies started using their own (unofficial) marketing phrases
  - “Group II Plus” and “Group III Plus”
  - Now used generally to mean “towards the high end of the group”
- Note: The word ‘Synthetic’ is not part of the API Classification
  - “Synthetic” is a marketing term, not a technical term
  - “Group III” can legally be labeled ‘synthetic’
Volatility

- Volatility depends on viscosity and molecular structure
  - Advantages for Group III and Group IV at low viscosity

![Graph showing volatility vs viscosity]

Base stock names and viscosity scales
Base stock names – API Group I

• Base stock names are brand names
  – Specific to each producing company
  – These are typical naming conventions:
• Solvent xxx Neutral (SxxxN, or SNxxx, or xxxSN, etc.)
  – Solvent from “Solvent Extracted”
  – xxx = viscosity
    • Saybolt Universal Seconds at 100°F
    • Approximately 4.6 times mm²/s at 210°F (~100°C)
  – Neutral from “Neutralization after Acid Washing”
    • First base stock refining technique
• HVI
  – Redwood Number 1 Seconds at 140°F (European)
• Bright Stock
  – Heaviest grade of base stock (~ S2500N = 650 Redwood)
  – xxx Bright Stock = SUS viscosity at 210°F (e.g., 150 Bright Stock)
    • Approximately 4.6 times mm²/s at 100°F (~40°C)
    • “Bright” because heavy aromatics often fluorescent

Base stock names – API Groups II, III, IV, & V

• Base stock names are brand names
  – Specific to each producing company
  – These are typical naming conventions:
• HC xxx
  – HydroCracked xxx
    • xxx viscosity usually mm²/s at 100°C
      – HC4
    • Sometimes equivalent “Neutral Number”
      – HC100
• MVI, HVI, VHVI and XHVI
  – Medium Viscosity Index Naphthenic (Group V)
  – High Viscosity Index Paraffinic (Group I)
  – Very High Viscosity Index Hydrocracked (Group II)
  – eXtra High Viscosity Index Hydrocracked (Group III)
• PAO x = usually some number related to mm²/s at 100°C
  – PAO 4 4 mm²/s at 100°C
  – PAO 45 4 mm²/s at 100°C
  – PAO 284 4 mm²/s at 100°C
### Base stock grade equivalents

<table>
<thead>
<tr>
<th>Grade</th>
<th>SUS* at 100°F</th>
<th>Redwood# at 140°F</th>
<th>mm²/s at 100°C</th>
<th>mm²/s at 40°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 75N</td>
<td>75</td>
<td>-</td>
<td>3.1</td>
<td>13</td>
</tr>
<tr>
<td>S100N</td>
<td>105</td>
<td>-</td>
<td>4.1</td>
<td>20</td>
</tr>
<tr>
<td>S150N</td>
<td>155</td>
<td>-</td>
<td>5.1</td>
<td>30</td>
</tr>
<tr>
<td>S325N</td>
<td>330</td>
<td>-</td>
<td>8.5</td>
<td>65</td>
</tr>
<tr>
<td>S600N</td>
<td>590</td>
<td>160</td>
<td>12.1</td>
<td>115</td>
</tr>
<tr>
<td>150 Bright Stock</td>
<td>2500</td>
<td>650</td>
<td>31.5</td>
<td>5000</td>
</tr>
</tbody>
</table>

*SUS = Saybolt Universal Seconds

#Approximate

150 SUS at 210°F

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### Base stock typical properties

![Base stock typical properties diagram]
### Typical lube base stock properties (solvent neutrals – API Group I)*

<table>
<thead>
<tr>
<th></th>
<th>Light (S100N)</th>
<th>Medium (S150N)</th>
<th>Heavy (S600N)</th>
<th>Bright Stock (S2500N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity at 100°C, mm²/s</td>
<td>4</td>
<td>5</td>
<td>12</td>
<td>32</td>
</tr>
<tr>
<td>Viscosity at 40°C, mm²/s</td>
<td>20</td>
<td>30</td>
<td>110</td>
<td>490</td>
</tr>
<tr>
<td>Viscosity Index</td>
<td>95</td>
<td>95</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>Pour Point, °C</td>
<td>-18</td>
<td>-18</td>
<td>-9</td>
<td>-18</td>
</tr>
<tr>
<td>Volatility, GCD % off at 371°C</td>
<td>20</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Volatility, NOACK</td>
<td>24</td>
<td>18</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Flash Point, °C</td>
<td>200</td>
<td>210</td>
<td>250</td>
<td>280</td>
</tr>
<tr>
<td>Saturates, mass percent</td>
<td>75</td>
<td>75</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>Sulfur, mass percent</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4</td>
<td>0.7</td>
</tr>
</tbody>
</table>

*Nominal, and not representative of any particular manufacturer

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### Typical lube base stock properties (hydrocracked – API Group II)*

<table>
<thead>
<tr>
<th></th>
<th>Light (100N)</th>
<th>Medium (200N)</th>
<th>Heavy (600N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity at 100°C, mm²/s</td>
<td>4</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Viscosity at 40°C, mm²/s</td>
<td>20</td>
<td>40</td>
<td>110</td>
</tr>
<tr>
<td>Viscosity Index</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Pour Point, °C</td>
<td>-18</td>
<td>-18</td>
<td>-18</td>
</tr>
<tr>
<td>Volatility, GCD % off at 371°C</td>
<td>16</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Volatility, NOACK</td>
<td>23</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Flash Point, °C</td>
<td>200</td>
<td>220</td>
<td>250</td>
</tr>
<tr>
<td>Saturates, mass percent</td>
<td>95</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>Sulfur, mass percent</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

*Nominal, and not representative of any particular manufacturer
### Typical lube base stock properties (hydrocracked – API Group III)*

<table>
<thead>
<tr>
<th></th>
<th>Light (100N)</th>
<th>Medium (150N)</th>
<th>Heavy (250N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity at 100°C, mm²/s</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Viscosity at 40°C, mm²/s</td>
<td>17</td>
<td>33</td>
<td>50</td>
</tr>
<tr>
<td>Viscosity Index</td>
<td>130</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>Pour Point, °C</td>
<td>-18</td>
<td>-18</td>
<td>-12</td>
</tr>
<tr>
<td>Volatility, GCD % off at 371°C</td>
<td>13</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Volatility, NOACK</td>
<td>240</td>
<td>250</td>
<td>260</td>
</tr>
<tr>
<td>Flash Point, °C</td>
<td>97</td>
<td>97</td>
<td>97</td>
</tr>
<tr>
<td>Saturates, mass percent</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sulfur, mass percent</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Nominal, and not representative of any particular manufacturer

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### Typical lube base stock properties (GTL – API Group III)*

<table>
<thead>
<tr>
<th></th>
<th>Very Light (GTL 3)</th>
<th>Light (GTL 4)</th>
<th>Medium (GTL 6)</th>
<th>Heavy (GTL 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity at 100°C, mm²/s</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Viscosity at 40°C, mm²/s</td>
<td>11</td>
<td>17</td>
<td>32</td>
<td>46</td>
</tr>
<tr>
<td>Viscosity Index</td>
<td>120</td>
<td>130</td>
<td>135</td>
<td>145</td>
</tr>
<tr>
<td>Pour Point, °C</td>
<td>-42</td>
<td>-33</td>
<td>-24</td>
<td></td>
</tr>
<tr>
<td>Volatility, GCD % off at 371°C</td>
<td>3</td>
<td>0.6</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Volatility, NOACK</td>
<td>34</td>
<td>9</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Flash Point, °C</td>
<td>200</td>
<td>230</td>
<td>240</td>
<td>270</td>
</tr>
<tr>
<td>Saturates, mass percent</td>
<td>98</td>
<td>97</td>
<td>97</td>
<td>96</td>
</tr>
<tr>
<td>Sulfur, mass percent</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Nominal, and not representative of any particular manufacturer
Typical lube base stock properties
(PAO – API Group IV)*

<table>
<thead>
<tr>
<th></th>
<th>Light (PAO 4)</th>
<th>Medium (PAO 6)</th>
<th>Heavy (PAO 10)</th>
<th>Very Heavy (PAO 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity at 100°C, mm²/s</td>
<td>4</td>
<td>6</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Viscosity at 40°C, mm²/s</td>
<td>18</td>
<td>30</td>
<td>65</td>
<td>1300</td>
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<tr>
<td>Viscosity Index</td>
<td>130</td>
<td>135</td>
<td>130</td>
<td>160</td>
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<tr>
<td>Pour Point, °C</td>
<td>-63</td>
<td>-63</td>
<td>-51</td>
<td>-30</td>
</tr>
<tr>
<td>Volatility, GCD % off at 371°C</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Volatility, NOACK</td>
<td>12</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Flash Point, °C</td>
<td>200</td>
<td>240</td>
<td>270</td>
<td>290</td>
</tr>
<tr>
<td>Saturates, mass percent</td>
<td>96</td>
<td>96</td>
<td>96</td>
<td>94</td>
</tr>
<tr>
<td>Sulfur, mass percent</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Nominal, and not representative of any particular manufacturer

Base stock recent trends

- Transition from API Group I to Group II continuing
  - Demand for higher quality (oxidation, dispersancy, etc.)
  - Specifications with sulfur restrictions
  - Demand for lower volatility in lower viscosity grades
- API Group I base stocks still have uses
  - Higher viscosity: Marine, railroad, gear oils
  - Lower viscosity: Transformer oils, process oils, spray oils
- Demand for API Group III (and Group III Plus) will increase
  - Growth of SAE 0W-xx and 5W-xx grades
- PAO capacity expected to increase
- Green base stocks are niche for now
  - Re-refined (derived from used oil re-cycling)
  - Bio-lubricants (derived from sugarcane, algae, etc.)
Base stock 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
- Chemical composition determines performance
  - Saturates and sulfur usually most important, but not the whole story
- 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
  - API BOIG’s are used to read-across testing
- Base stock research continuing
  - Develop better analytical test methods
  - Improve performance predictions
  - Demand for higher quality expected to continue