Base Oil and Wax production

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Lubricant Story

• 1400 BC, beef and mutton fat (tallow) being applied to lubricate chariot axles. Very little changed over the next 3000 years except, that the oils sometimes came from more exotic animals such as whales.

• In 1852 petroleum-based oils first became available. They were not widely accepted at first because they did not perform as well as many of the animal-based products. Raw crude did not make very good lubricant.

• But as the demand for automobiles grew, so did the demand for better lubricants.

• Lubricant manufacturers learned soon which crudes made the best lubricants.

• By 1923 the Society of Automotive Engineers classified engine oils by viscosity: light, medium, and heavy. Engine oils contained no additives and had to be replaced every 800-1000 miles.

• In the 1920s more lubrication manufacturers started “processing” their base oils to improve their performance.

• HC technologies were commercialized for lube poruction in late ’50 and dewaxing was in ,’70
Lubes

- Automotive: engine oils, automatic transmission fluids (ATF’s), gear-oils
- Industrial: machine oils, greases, electrical insulating oils, gas turbine oils
- Pharmacy/cosmetics: white oils, paraffinicum liquidum
- Provisioning: food grade oils, lining of food containers, cover of food, etc.
Lube Refinery

- Why beneficial to produce base stocks and waxes?
- What are the products and which properties are important?
- Which types of processes?
- Global market and changes
Refinery output = global demand

- Gasoline: 20% - 50%
- Distillates (Diesel / HO): 50% - 20%
- Jet - Kerosene: 10% - 12%
- Solvents / Chem: 8% - 15%
- LPG / gases: 5% - 10%
- Heavy Fuel Oil: 5% - 10%
- Asphalt: 5% - 8%
- Base Oils: 1%
- Other: 1%

Sources: IEA, EIA, My Energy

Base oil demand is small compared to transportation fuels and other products

Worldwide = 635 Crude Oil Refineries
142 Produce Base Oils
Base oils from ~20% of refineries
... only 1% of refining volume

And .. additional refinery capital investment required
Global Lubricant Consumption by Region

Global Lubricant Consumption, 2004-2011 (MMT)

Global Lubricant Consumption, 2004-2011 by Region

Total: 38.6 MMT

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Feedstocks and product portfolio

Feedstocks: Vacuum distillates and residues

Products and intermediers:
- Base oils
- Waxes
- Paraffins
- Slack-waxes
- Foots oils
- Others: Side products, solvented distillates, dewaxed distillates, etc.
Main quality parameters:

- Viscosity
- Volatility (Noack)
- Viscosity index (VI)
- Pour point: the temperature at which the fluid ceases to pour and is nearly a solid (typically the pour point ranges from -6 to -24°C for heavy to light neutrals)
- Cloud point: the temperature at which the first wax crystals appear
- Saturates, aromatics, naphthenes content
- Color (change appearance in presence of light)
- Stability (change appearance in presence of heat)
- Melting point (waxes)
## Base Oils API Groups

<table>
<thead>
<tr>
<th>API Group</th>
<th>% saturates</th>
<th>% sulfur</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>&lt; 90 % sats <em>and/or</em></td>
<td>&gt; 0.03% S</td>
<td>≥ 80 and &lt; 120</td>
</tr>
<tr>
<td>II</td>
<td>≥ 90 % sats <em>and</em></td>
<td>≤ 0.03% S</td>
<td>≥ 80 and &lt; 120</td>
</tr>
<tr>
<td>III</td>
<td>≥ 90 % sats <em>and</em></td>
<td>≤ 0.03% S</td>
<td>&gt; 120</td>
</tr>
<tr>
<td>IV</td>
<td></td>
<td></td>
<td>Poly-alpha-olefins (PAO)</td>
</tr>
<tr>
<td>V</td>
<td>Basestocks  not included in Groups I – IV</td>
<td></td>
<td>Source: API 1509 Appendix E</td>
</tr>
</tbody>
</table>
Feedstock composition

- n-Paraffin (straight chain)
- iso-Paraffin (branched chain)
- Naphthene (cyclo paraffin)
- Benzothiophene (sulfur heterocyclic)
- Dialkyl Sulfide

(Mol.wt. 1248)
## Effect of molecular types

<table>
<thead>
<tr>
<th>Designation</th>
<th>Viscosity Index</th>
<th>Pour Point</th>
<th>Resistance to Oxidation</th>
<th>Value as Base Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>n</em>-paraffins</td>
<td>✅ ✓ ✓ ✓</td>
<td>✓</td>
<td>✅ ✓ ✓ ✓</td>
<td>✅ ✓ ✓ ✓</td>
</tr>
<tr>
<td>iso-paraffins</td>
<td>✅ ✓ ✓</td>
<td>✓ ✓ ✓</td>
<td>✅ ✓ ✓ ✓</td>
<td>✅ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Mono-naphthenes</td>
<td>✓ ✓</td>
<td>✓ ✓ ✓</td>
<td>✅ ✓ ✓ ✓</td>
<td>✅ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Poly-naphthenes</td>
<td>✓ ✓</td>
<td>✓ ✓ ✓</td>
<td>✓ ✓ ✓</td>
<td>Nil</td>
</tr>
<tr>
<td>Aromatics</td>
<td>✓</td>
<td>✓ ✓ ✓</td>
<td>✓</td>
<td>Nil</td>
</tr>
</tbody>
</table>
Solvent processes

Main three process steps

- Crude distillation to Light-, Medium- and Heavy feed fractions
- Remove the unwanted aromatics – solvent extraction
- Remove paraffins and waxes – solvent dewaxing
# Quality parameter controls

<table>
<thead>
<tr>
<th>Property</th>
<th>Where controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity</td>
<td>Crude distillation isolates heavy molecules and creates primary viscosity grades</td>
</tr>
<tr>
<td>VI</td>
<td>Solvent extraction (aromatics removal) + VI increases as aromatics are removed</td>
</tr>
<tr>
<td>Saturates</td>
<td>Solvent extraction (aromatics removal) + Saturates increase as aromatics are removed</td>
</tr>
<tr>
<td>Pour Point</td>
<td>Solvent dewaxing (wax removal) + Pour point decreases as wax is removed</td>
</tr>
</tbody>
</table>
# Molecules and processes

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Structure</th>
<th>Base Stock Quality Affected</th>
<th>Process Involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-Paraffin</td>
<td><img src="image" alt="N-Paraffin Structure" /></td>
<td>High Pour, VI No S and CCR</td>
<td>Dewaxing</td>
</tr>
<tr>
<td>1-Paraffin</td>
<td><img src="image" alt="1-Paraffin Structure" /></td>
<td>High VI and Sats Medium Pour</td>
<td></td>
</tr>
<tr>
<td>2-Ring Naphthene</td>
<td><img src="image" alt="2-Ring Naphthene Structure" /></td>
<td>Medium VI, Low Pour, High Acids</td>
<td>Extraction, Hydrofinishing</td>
</tr>
<tr>
<td>1-Ring Aromatic</td>
<td><img src="image" alt="1-Ring Aromatic Structure" /></td>
<td>Medium to High VI</td>
<td>Extraction</td>
</tr>
<tr>
<td>Multi-Ring Naphthene</td>
<td><img src="image" alt="Multi-Ring Naphthene Structure" /></td>
<td>Low VI, Low Pour, High Acids</td>
<td>Extraction, Hydrofinishing</td>
</tr>
<tr>
<td>Multi-Ring Aromatic</td>
<td><img src="image" alt="Multi-Ring Aromatic Structure" /></td>
<td>Low VI, Low Pour</td>
<td>Extraction</td>
</tr>
<tr>
<td>Organic Sulfur</td>
<td><img src="image" alt="Organic Sulfur Structure" /></td>
<td>Good Stability, Antioxidant</td>
<td>Hydrofinishing</td>
</tr>
<tr>
<td>Organic Nitrogen</td>
<td><img src="image" alt="Organic Nitrogen Structure" /></td>
<td>Poor Stability</td>
<td>Hydrofinishing</td>
</tr>
<tr>
<td>Aliphatic Sulfur and Nitrogen</td>
<td><img src="image" alt="Aliphatic Sulfur and Nitrogen Structure" /></td>
<td>Removed by Hydrofinishing</td>
<td>Hydrofinishing</td>
</tr>
<tr>
<td>Asphaltenes</td>
<td><img src="image" alt="Asphaltenes Structure" /></td>
<td>Condensed Multi-Rings, Poor Color, High CCR</td>
<td>Distillation, Deasphalting</td>
</tr>
</tbody>
</table>

**DEWAXING**

**EXTRACTION**
Process solvent and ratios

Solvent Deasphalting
Solvents: **Propane** to Heptane $C_3 - C_7$
Typical solvent ratio (C$_3$ case): 1:3,4-3,6 t/t

Solvent Treating (Aromatic removal)
Solvents: Furfural, Phenol,
**NMP (N-methyl pyrolidone)**
Typical solvent ratio (NMP case): 1:1,75-2,25 t/t

Solvent Dewaxing and Deoiling
Solvents: **MEK, Toluene, Acetone**
Typical solvent ratio (MEK-T): 1:3 - 1:5 t/t
Solvent Composition: MEK 40-45%, T: 55-60%
Process types and steps

- **Solvent processes**
  - Vacuum distillation
  - Solvent Deasphalting
  - Solvent Extraction
  - Solvent Dewaxing
  - Solvent Deoiling
  - Hydrotreating
  - Clay treating

- **Catalytic processes**
  - Vacuum distillation
  - Base Oil Hydrocracking
  - Cat. Dewaxing / Isodewaxing
  - Hydrotreating
Base Oil Hydrocracking & Isodewaxing

- Catalytic Lube Hydrocracking & Catalytic Dewaxing

1) Hydrocracking

2) Hydrodewaxing

3) Re-fractionation and blending

Diagram showing the process flow for Base Oil Hydrocracking & Isodewaxing.
Group III production on HCU base

- Base case: VGO Hydrocracker unit (HCU) exists for Diesel production
- Unconverted Oil (HCU Residue) is applicable for Base Oil Production
- Only a Hydrodewaxing unit is needed, Lube Hydrocracker unit is not needed
<table>
<thead>
<tr>
<th>Property</th>
<th>Process where controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity</td>
<td>Crude distillation and back-end re-distillation after hydrocracking / hydodewaxing</td>
</tr>
<tr>
<td>VI</td>
<td>Hydrocracking</td>
</tr>
<tr>
<td></td>
<td>+ VI increases as aromatics are removed</td>
</tr>
<tr>
<td>Saturates</td>
<td>Hydrocracking</td>
</tr>
<tr>
<td></td>
<td>+ Sats increase as aromatics are removed</td>
</tr>
<tr>
<td>Pour Point</td>
<td>Hydrodewaxing</td>
</tr>
<tr>
<td></td>
<td>+ Pour point decreases as wax is removed</td>
</tr>
</tbody>
</table>
Group III⁺ production on GTL process

- Fischer-Tropsch process base
- F-T HCs products are a white waxy crude for upgrading
- Group III⁺ quality Base Oils can be produced next to the fuels
Typical API Group composition

<table>
<thead>
<tr>
<th>Category</th>
<th>Group I</th>
<th>Group II</th>
<th>Group III</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>$80 \leq VI &lt; 120$</td>
<td>$80 \leq VI &lt; 120$</td>
<td>$VI \geq 120$</td>
</tr>
<tr>
<td>Saturates</td>
<td>$&lt; 90%$</td>
<td>$\geq 90%$</td>
<td>$\geq 90%$</td>
</tr>
<tr>
<td>Sulphur</td>
<td>$&gt; 0.03%$</td>
<td>$\leq 0.03%$</td>
<td>$\leq 0.03%$</td>
</tr>
</tbody>
</table>

Composition:
- iso-paraffins
- naphthenes
- n-paraffins
- aromatics
- polar compounds

Narrow chemical spectrum
Composition differences

Group I

Group III
API Groups - What’s better?

Same Labels, New Perceptions
Regarding What’s “Better”?

Naphthenics
- Group I
- Group II
- Group III
- Group III+
- PAO

- Better solvency
- Higher viscosity grades
- Poor solvency (absence of aromatics, naphthenes)

Fine oxidation stability
(95 VI)

Better oxidation stability
(higher saturates, higher VI)
Transportation-related lubrication is largest market at around 60% of global applications.

Industrial / grease applications are ~ 30%

Non-lubricating applications ("process oils") are ~ 10%

Sources: My Energy Databases, Fuchs Lubricants, Kline & Company
Nearly 150 KB/D of Group I capacity could be decommissioned during this decade, and another 100-150 KB/D is “At Risk” from low margins/refinery shutdowns by 2030
Base Oil – Changes in global production

Changes in Base Oil Capacity by Group, 2000-2017

Changes in Base Oil Capacity by Viscosity, 2000-2017

Source: Kline
Base Oil Global Demands

2018 Base Oil Capacity

- Group I: 43%
- Group II: 35%
- Group III: 9%
- Naphthenic: 13%

Source: My Energy databases & analysis

Group I 23500 mT
Group II 19500 mT
Group III 7000 mT
Naphthenic 5000 mT

Total ~ 55 MMT
~ 80% avg. global capacity utilization
(supply ~ 44 MMT)
Thank you!

Thank You for Your Attention!

Q & A