Group III Base Stock Trends in Europe: The Advantages and Opportunities of Higher VI Group III Base Stocks

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Jan Trocki and Mike Brown
SK Lubricants
Agenda

- Group III market status
- Growth drivers in Europe
- Future PCMO influences
- Impact on Group III demands
- Higher VI Group III base stocks
- Formulation benefits
- Base oil characteristics
- Conclusion
Global Base Oil Capacity by API Group

- Total Nameplate Capacity: 934,080 bpd
- Global Group III: 60,080 bpd

Source: Lubes & Greases World Base Stock Guide
Global Top 10 Group III Manufacturers

Source: Lubes&Greases World Base Stock Guide
Gp III Entered with Extended-ODIs

- 10,000km / 2 per year
- 15,000km / 1 year
- 30,000km / 2 years

- 1980s
- 1995
- 2010

5W-40
10W-30
10W-40

0W-30
5W-30
5W-40

0W-30
5W-30
5W-30
5W-30
In-Use Fleet Filled with 5W-XX

Car Fleet by Age (EU15)

- >10 years: 32%
- ≤5 years: 35%
- 5 to 10 years: 33%

Average Car Age by Country

<table>
<thead>
<tr>
<th>Country</th>
<th>Average Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>7.4</td>
</tr>
<tr>
<td>BE</td>
<td>7.8</td>
</tr>
<tr>
<td>DK</td>
<td>9.1</td>
</tr>
<tr>
<td>FI</td>
<td>10.5</td>
</tr>
<tr>
<td>FR</td>
<td>8.1</td>
</tr>
<tr>
<td>DE</td>
<td>8.1</td>
</tr>
<tr>
<td>EL</td>
<td>10.1</td>
</tr>
<tr>
<td>IT</td>
<td>7.5</td>
</tr>
<tr>
<td>PT</td>
<td>8.6</td>
</tr>
<tr>
<td>SE</td>
<td>9.4</td>
</tr>
<tr>
<td>UK</td>
<td>6.7</td>
</tr>
</tbody>
</table>

Source: ACEA
Growth of 0W-XX & 5W-XX in DIFM channels

**OEM Franchise Workshops**

- Germany: 71%
- France: 53%
- Italy: 39%
- UK: 39%
- Spain: 20%
- Portugal: 39%
- Poland: 61%
- Russia: 55%

**Independent Workshops**

- Germany: 49%
- France: 33%
- Italy: 30%
- UK: 19%
- Spain: 21%
- Portugal: 20%
- Poland: 35%
- Russia: 47%

**Legend:**
- Blue: SAE 0W-XX & 5W-XX
- Red: SAE 10W-XX, 15W-XX & 20W-XX
Increasing Oil Stress

Source: ACEA, Surveys

Source: ACEA, Surveys
Demand for Reduced Emissions

Source: ACEA
Improving Fleet Fuel Consumption

CO₂ emissions from new cars

Source: ACEA

gCO₂/km for gasoline & diesel cars

Source: ACEA
The Fuel Economy Challenge

Source: EU Statistics
Yubase Plus contribution to fuel economy

MB M111 FE test

SAE 5W-40

% FE vs RL191

Yubase

Yubase Plus

MB 229.5 min.
PCMO Demands Will Increase Group III Use

- Legislation
- Consumers
- OEMs

Fuel economy
- Maintain ODIs
- Protect Exhaust After treatment
- Biofuels
- Increasing Oil Stress
Group III will continue to grow in PCMO

Source: Lubrizol (ICIS 2009) and estimates
Group III Production Capacity Will Double

**Source: 2009 Lubes 'N' Greases**

**Current Year: 2010**
- SK Lubricants 40%
- S-Oil 15%
- Petronas 9%
- Neste 8%
- Suncor (P-C) 3%
- Others 9%
- Asia (non-Mer) 16%

**Global Group III: 60,080 bpd**

**Within 5 years**
- S-Oil Expansion: 10,000 bpd (6/2010)
- Takreer–Neste: 10,000 bpd (2013)
- SKL: 2 new 10,000 bpd plants by 2015

**+ 76,500 bpd new plants in 5 yrs**
How Will the Market Absorb New Capacity?

• OEMs take several years to give new approvals.

• Base Stock Interchange between manufacturers is a big issue with
  – API, ATIEL
  – OEMs
  – Additive companies
  – Marketers

• However, there are advantages and opportunities for the stakeholders to develop products with higher VI Group III base stocks.
YUBASE and YUBASE plus

- SKL YUBASE and YUBASE plus base stocks have different viscosities and other properties which formulators use in higher performance engine oils.

<table>
<thead>
<tr>
<th>YUBASE</th>
<th>4</th>
<th>4 plus</th>
<th>6</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>plus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KVis @ 100°C, cSt**</td>
<td>4.22</td>
<td>4.13</td>
<td>6.45</td>
<td>6.44</td>
</tr>
<tr>
<td>Viscosity Index**</td>
<td>125</td>
<td>133</td>
<td>131</td>
<td>143</td>
</tr>
<tr>
<td>CCSVis @-30°C, cP**</td>
<td>1,525</td>
<td>1,138</td>
<td>4,973</td>
<td>3,738</td>
</tr>
<tr>
<td>Noack volatility, wt%**</td>
<td>15.0</td>
<td>13.0</td>
<td>7.1</td>
<td>5.4</td>
</tr>
<tr>
<td>Paraffins + 1 ring paraffins, vol %</td>
<td>80.5</td>
<td>93.1</td>
<td>81.5</td>
<td>91.3</td>
</tr>
</tbody>
</table>

** Average properties of 12 months production.
New Higher VI Stocks: Lower Volatility

Higher VI components at the correct kinematic viscosities for engine oils possess lower Noack volatilities.

- YUBASE 4
  123 VI
  15.2% Noack

- YUBASE 4 plus
  132 VI
  13.5% Noack

- YUBASE 6
  133 VI
  7.3% Noack

- YUBASE 6 plus
  145 VI
  6.8% Noack

** See Henderson, H.E. et al in SAE 98252 and ICIS London 2002
Low temperature properties in the mini-rotary viscometer.

- Base Stocks with 0.3 wt% pour point depressant added

Lower volatility and improved pumpability

SAE 5W–40 multigrade engine oil

<table>
<thead>
<tr>
<th>Formula [wt%]</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>YUBASE 4</td>
<td>55.60</td>
<td>-</td>
<td>38.90</td>
</tr>
<tr>
<td>YUBASE 4 plus</td>
<td>-</td>
<td>38.40</td>
<td>16.70</td>
</tr>
<tr>
<td>YUBASE 6</td>
<td>19.20</td>
<td>37.20</td>
<td>19.20</td>
</tr>
<tr>
<td>VII</td>
<td>12.60</td>
<td>11.80</td>
<td>12.60</td>
</tr>
<tr>
<td>DI Additives</td>
<td>balance</td>
<td>balance</td>
<td>balance</td>
</tr>
</tbody>
</table>

### Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vis. @100°C, cSt</td>
<td>13.84</td>
<td>13.79</td>
<td>13.81</td>
</tr>
<tr>
<td>CCS @-30°C, cP</td>
<td>5,600</td>
<td>5,570</td>
<td>5,180</td>
</tr>
<tr>
<td>MRV @-35°C, cP</td>
<td>35,500</td>
<td>32,540</td>
<td>30,610</td>
</tr>
<tr>
<td>Noack, wt%</td>
<td>11.1</td>
<td>9.5</td>
<td>9.7</td>
</tr>
<tr>
<td>HTHSV @ 150°C, cP</td>
<td>3.71</td>
<td>3.72</td>
<td>3.72</td>
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</table>

API SM/CF, ACEA A3/B3/B4/C3-04 PCDO
Reduce VII Treat and Oil Volatility

SAE 5W–30 multigrade engine oil

<table>
<thead>
<tr>
<th>Formula [wt%]</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>YUBASE 4</td>
<td>78.30</td>
<td>-</td>
</tr>
<tr>
<td>YUBASE 4 plus</td>
<td>-</td>
<td>54.40</td>
</tr>
<tr>
<td>YUBASE 6</td>
<td>-</td>
<td>25.00</td>
</tr>
<tr>
<td>VII</td>
<td>9.10</td>
<td>8.00</td>
</tr>
<tr>
<td>Additives</td>
<td>balance</td>
<td>balance</td>
</tr>
</tbody>
</table>

**Properties**

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Oil Blend Vis. @100°C, cSt</td>
<td>4.2</td>
<td>4.7</td>
</tr>
<tr>
<td>Vis. @100°C, cSt</td>
<td>10.49</td>
<td>10.50</td>
</tr>
<tr>
<td>Viscosity Index</td>
<td>171</td>
<td>172</td>
</tr>
<tr>
<td>CCS @-30°C, cP</td>
<td>4,110</td>
<td>4,130</td>
</tr>
<tr>
<td>Noack, wt%</td>
<td>12.8</td>
<td>10.1</td>
</tr>
<tr>
<td>HTHSV @ 150°C, cP</td>
<td>3.09</td>
<td>3.13</td>
</tr>
</tbody>
</table>

API SM/CF, ACEA A5/B5-04 PCDO
Replace PAO 6 Correction Fluid

SAE 5W–30 multigrade heavy duty diesel engine oil

<table>
<thead>
<tr>
<th>Formula [wt%]</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAO 6</td>
<td>30.00</td>
<td>10.0</td>
<td>-</td>
</tr>
<tr>
<td>YUBASE 4</td>
<td>39.30</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>YUBASE 4 plus</td>
<td>-</td>
<td>44.30</td>
<td>43.80</td>
</tr>
<tr>
<td>YUBASE 6</td>
<td>-</td>
<td>15.0</td>
<td>-</td>
</tr>
<tr>
<td>YUBASE 6 plus</td>
<td>-</td>
<td>-</td>
<td>25.50</td>
</tr>
<tr>
<td>Additives</td>
<td>balance</td>
<td>balance</td>
<td>balance</td>
</tr>
</tbody>
</table>

Properties

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Vis. @100°C, cSt</td>
<td>11.6</td>
<td>11.6</td>
<td>11.8</td>
<td>9.3~&lt;12.5</td>
</tr>
<tr>
<td>CCS @-30°C, cP</td>
<td>6,150</td>
<td>6,050</td>
<td>5,900</td>
<td>Max. 6,600</td>
</tr>
<tr>
<td>Noack, wt%</td>
<td>11.6</td>
<td>11.8</td>
<td>11.3</td>
<td>Max. 12.0</td>
</tr>
<tr>
<td>HTHS @ 150°C, cP</td>
<td>3.54</td>
<td>3.56</td>
<td>3.60</td>
<td>Min. 3.5</td>
</tr>
</tbody>
</table>

ACEA E6-08 (13% max Noack), MB228.51 (12.0% max Noack)
And potential in top tier products

YUBASE plus application in SAE 0W-30/0W-40 grades

<table>
<thead>
<tr>
<th>Test</th>
<th>Engine Properties</th>
<th>Viscosity grade</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>VW TDi</td>
<td>Piston deposits, ring cleanliness</td>
<td>0W-40</td>
<td>Pass</td>
</tr>
<tr>
<td>OM 646LA</td>
<td>Cam wear, bore polishing</td>
<td>0W-30</td>
<td>Pass</td>
</tr>
<tr>
<td>M111 FE</td>
<td>Fuel economy</td>
<td>0W-40</td>
<td>Pass (2.20%)</td>
</tr>
<tr>
<td>DV4TD</td>
<td>Soot induced viscosity increase</td>
<td>0W-40</td>
<td>Pass</td>
</tr>
<tr>
<td>OPEL RNT</td>
<td>Valve train wear</td>
<td>0W-30</td>
<td>Pass</td>
</tr>
</tbody>
</table>

✓ Full synthetic passenger car diesel and gasoline applications
✓ Possible major European OEMs performance and GM dexos 2
✓ High Fuel Economy value proposition for customers
Approaching quality of PAO 4 and GTL stocks.

Group III+: 130–133 VI
Group III: 120–128 VI

Higher VI Group III+ Base Stocks
The challenge of Base Oil Interchange

- Considerable variations in base stock compositions present a challenge to adding more BOI guidelines.

![Graph showing the relationship between Paraffins + Monocycloparaffins, vol %, D2786 and Viscosity Index. The graph is divided into two groups: Group II, II+ and Group III, III+.]

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Summary

- Group III base stocks enable higher performance standards in Europe and will contribute to future CO₂ reductions from PCMO.

- Base stock manufacturers continue to search for innovative ways to maximize iso-paraffins in base stocks.

- Blend studies with European style formulations reveal advantages and opportunities for higher VI base stocks: lower volatility, easier pumpability, replace PAO 6 correction fluid.

- Higher VI base stocks are being engineered into new top tier products meeting the latest specifications for fuel economy grades.

- Considerable variations in higher VI base stock compositions present a challenge to adding more BOI guidelines.
Jan Trocki  
SK Lubricants Europe B. V.  
JanTrocki@SKLubricants.com  
44 (0) 1285 750590

Mike Brown  
SK Lubricants Americas  
Mike.Brown@SK-Houston.com  
908-751-5030

www.yubase.com