Dodecene-based Synfluid® PAOs: Volatility, Viscosity Index and CCS Advantages!

STLE 2016 Annual Meeting Commercial Marketing Forum

Ken Hope, Ph.D., CLS
Topics

• What are Dodecene-based PAOs?
  – Chevron Phillips Chemical’s history of PAOs
  – Process for making dodecene-based PAOs

• Current Industry Challenges
  – Volatility, viscosity index, CCS viscosity
  – Fuel economy

• Advantages of Dodecene-based PAOs
  – Feedstock availability
  – Trim stock for engine oils for volatility and CCS
  – VI support of energy efficiency and cleanliness
  – Base stock interchangeability
Chevron Phillips Chemical’s History of PAOs

1980: Gulf Oil first to commercialize PAO

1985: Chevron Gulf merger

1995: Chevron first to produce dodecene based PAOs

2000: Chevron Phillips formed and 10kMta expansion

2011: Chevron Phillips acquires Neste PAO assets

2011: Chevron Phillips begins Synfluid® mPAO production

2017: Chevron Phillips 10kMta expansion

2017: Chevron Phillips 1500kMta ethylene unit
PAO Production Process

1-C_{10} → Catalyst A → C_{20} + C_{30} + C_{40} .... → Catalyst B → C_{20} + C_{30} + C_{40} ....

n-Alpha Olefin

Catalyst A: Unsaturated Polyalphaolefins
Catalyst B: Isoparaffinic Synthetic Hydrocarbons (PAO)
PAO Production Process

1-$\text{C}_{12}^-$

$n$-Alpha Olefin

Catalyst A

$\text{C}_{24}^-$ + $\text{C}_{36}^-$ + $\text{C}_{48}^-$ ....

Unsaturated Polyalphaolefins

Catalyst B

$\text{C}_{24}^-$ + $\text{C}_{36}^-$ + $\text{C}_{48}^-$ ....

Isoparaffinic Synthetic Hydrocarbons (PAO)

2.5 5 6 HVI 7 8 HVI 9
Industry Challenges

Energy Efficiency Need

- Increased Corporate Average Fuel Economy limits (35.5 mpg today to a 2025 target of 54 mpg)
  - Lower HTHS = lower viscous drag
- EU CO₂ limits (2020/2021 target of 95 g CO₂ / km)
- Focus on lowering the viscosity of the engine oil (lower HTHS ≡ lower friction)
- Balance of wear (durability) and fuel economy

**US CAFE Limits 2016-2025**

**EU Fuel Efficiency Targets**


HTHS – High Temperature High Shear viscosity (ASTM D4683)
HTHS and CCS Trends from Group III, III+ and IV Base Stocks

- Low viscosity engine oils require a balance of properties including:
  - HTHS viscosity
  - Low Noack volatility
  - Low CCS @ -35°C

- Reducing the HTHS viscosity is a means to achieve improved fuel economy, maintaining a higher HTHS as the CCS viscosity decreases should provide a balance of fuel economy with wear and durability benefits

- HTHS – High Temperature High Shear viscosity (ASTM D4683)
- CCS – Cold Cranking Simulator viscosity (ASTM D5293)
Volutility and CCS Trends Derived from Group III, III+ and IV Base Stocks

- Low viscosity engine oils require a balance of properties including:
  - Low CCS viscosity
  - Low Noack volatility

- C12 based PAOs outperform traditional C10 based PAOs on these properties

- With better quality base oils there are inherent advantages:
  - Oxidative stability (oil life)
  - Higher VI (better cleanliness and faster lubrication to critical parts during startup)

- HTHS – High Temperature High Shear viscosity (ASTM D4683)
- CCS – Cold Cranking Simulator viscosity (ASTM D5293)
## Synfluid® PAO 6 vs. Synfluid® PAO 5 & PAO 6 HVI

<table>
<thead>
<tr>
<th>Property</th>
<th>Synfluid® PAO 5</th>
<th>Synfluid® PAO 6 HVI</th>
<th>Synfluid® PAO 6</th>
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<tbody>
<tr>
<td>Kinematic Viscosity, cSt @ 100°C</td>
<td>5.1</td>
<td>5.9</td>
<td>5.9</td>
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<td>Kinematic Viscosity, cSt @ 40°C</td>
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<td>29.1</td>
<td>30.5</td>
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<td>7000</td>
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<tr>
<td>CCS, cP @-35°C</td>
<td>3018</td>
<td>3571</td>
<td>3715</td>
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<tr>
<td>Viscosity Index</td>
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<tr>
<td>Pour Point, °C</td>
<td>-47</td>
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<td>-63</td>
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<tr>
<td>Flash Point (COC), °C</td>
<td>246</td>
<td>249</td>
<td>244</td>
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<tr>
<td>Fire Point (COC), °C</td>
<td>278</td>
<td>291</td>
<td>274</td>
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<tr>
<td>Volatility, Noack, wt %</td>
<td>5.5</td>
<td>4.9</td>
<td>6.6</td>
</tr>
<tr>
<td>Specific Gravity, 15.6°/15.6°C</td>
<td>0.8244</td>
<td>0.8256</td>
<td>0.8277</td>
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<td>Total Acid Number</td>
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<tr>
<td>Appearance</td>
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<tr>
<td>Color, Pt-Co</td>
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</tbody>
</table>

- **-40 °C Kinematic Viscosity, viscosity index, CCS & Noack Volatility** are superior for PAO 6 HVI and PAO 5
### Synfluid® PAO 8 vs. Synfluid® PAO 7 & PAO 8 HVI

<table>
<thead>
<tr>
<th>Property</th>
<th>Synfluid® PAO 7</th>
<th>Synfluid® PAO 8 HVI</th>
<th>Synfluid® PAO 8</th>
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<tbody>
<tr>
<td>Kinematic Viscosity, cSt @ 100°C</td>
<td>7.0</td>
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<td>Kinematic Viscosity, cSt @ 40°C</td>
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<tr>
<td>CCS, cP @-35°C</td>
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<tr>
<td>Viscosity Index</td>
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<tr>
<td>Pour Point, °C</td>
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<td>-55</td>
</tr>
<tr>
<td>Flash Point (COC), °C</td>
<td>263</td>
<td>267</td>
<td>263</td>
</tr>
<tr>
<td>Fire Point (COC), °C</td>
<td>294</td>
<td>300</td>
<td>292</td>
</tr>
<tr>
<td>Volatility, Noack, wt %</td>
<td>3.6</td>
<td>3.3</td>
<td>3.6</td>
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<tr>
<td>Specific Gravity, 15.6°/15.6°C</td>
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<tr>
<td>Bromine Index</td>
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<td>Color, Pt-Co</td>
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</tr>
</tbody>
</table>

- Viscosity Index & CCS are superior for PAO 8 HVI and PAO 7
Advantages of Dodecene-based PAOs

- **Feedstock availability**
  - An overwhelming majority of decene is used in PAO
  - Dodecene expands the available feed for PAO

- **Product Properties**
  - Trim stock for engine oils for volatility and CCS
  - VI support with energy efficiency and cleanliness

- **Base Stock Interchangeability**
  - Many have developed the ability to utilize Dodecene-based PAO in engine oil and other applications
  - Test data development to allow for base stock interchangeability is continuing

![NAO Product Distribution Graph](image-url)
Summary

• **Industry Challenges Driven by Energy Demands**
  – Places more stress on the oil
  – Increases demand for high-quality base oils
  – Key features of dodecene-based PAOs fit nicely with physical property needs (Noack, VI, CCS etc.)

• **Long History of Dodecene-based PAOs**
  – Chevron Phillips Chemical has been manufacturing these products for over 20 years
  – Base Oil Interchange remains a challenge but is being addressed
  – Future expansions will likely include feedstock versatility
Thank You!