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

STLE 2016 Annual Meeting
Commercial Marketing Forum

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Chevron Phillips Chemical Company LLC

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

Members of the joint-venture management team watch as Chief Executive Officer Jim Gallogly flips a coin to decide the name of the new company. From left to right: Tim Taylor, Scott Meyer, Greg Garland, Mike Packer, Gallogly, Kent Potter and Bob Hunt.

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

$1\text{-}C_{10}^{=}$

n-Alpha Olefin

Catalyst A

$C_{20}^{=} + C_{30}^{=} + C_{40}^{=} \ldots.$

Unsaturated Polyalphaolefins

Catalyst B

$C_{20} + C_{30} + C_{40} \ldots.$

Isoparaffinic Synthetic Hydrocarbons (PAO)

PAO Production Process

$1\text{-}C_{12}^{=}$ — *n*-Alpha Olefin

Catalyst A

$C_{24}^{=} + C_{36}^{=} + C_{48}^{=} \ldots$ — *Unsaturated Polyalphaolefins*

Catalyst B

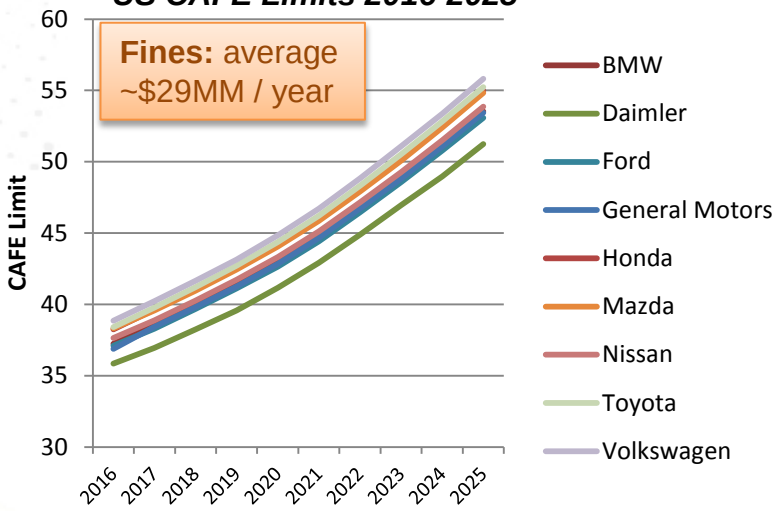
$C_{24} + C_{36} + C_{48} \ldots$ — *Isoparaffinic Synthetic Hydrocarbons (PAO)*

Industry Challenges

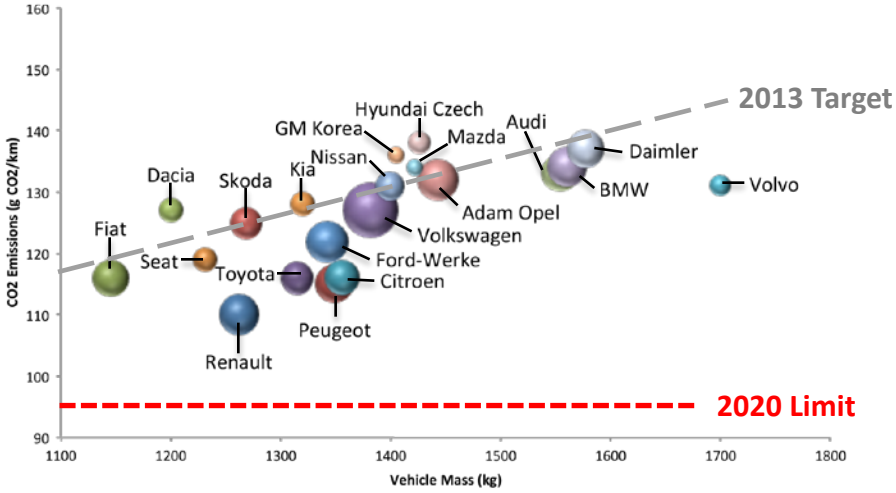
Energy Efficiency Need

- Increased Corporate Average Fuel Economy limits (35.5 mpg today to a 2025 target of 54 mpg)
  - Lower HTHS = lower viscous drag
- EU CO_2 limits (2020/2021 target of 95 g CO_2 / 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[1]



EU Fuel Efficiency Targets[2]

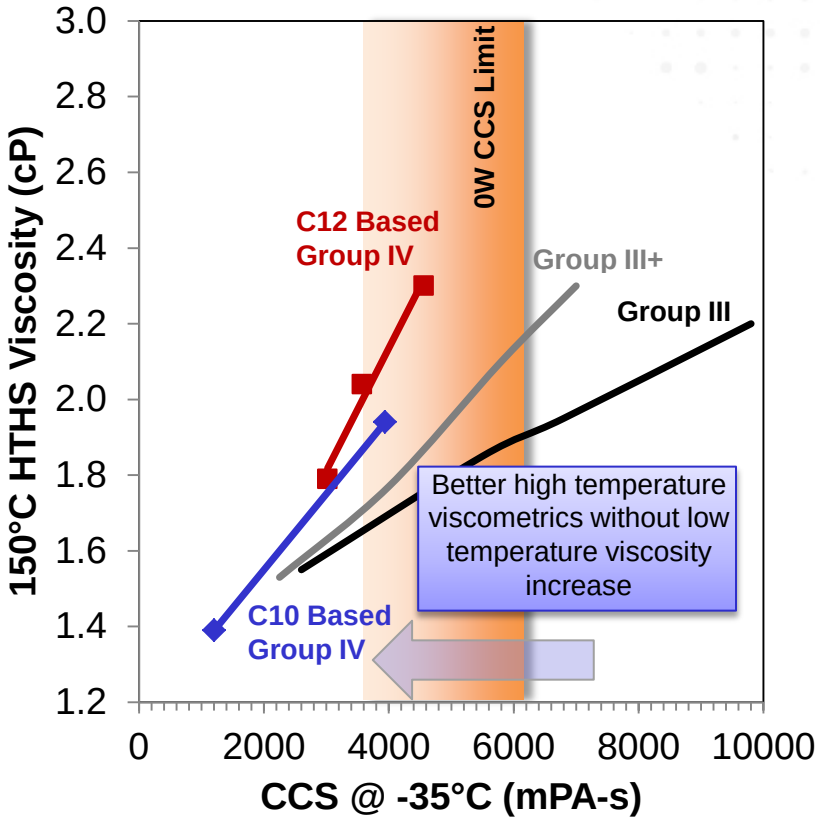


1: www.nhtsa.gov CAFE Fuel Economy Standards and Midterm Evaluation for Light-Duty Vehicles, MYs 2022-2025
2: http://ec.europa.eu/clima/documentation/transport/vehicles/cars/index_en.htm
HTHS – High Temperature High Shear viscosity (ASTM D4683)

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

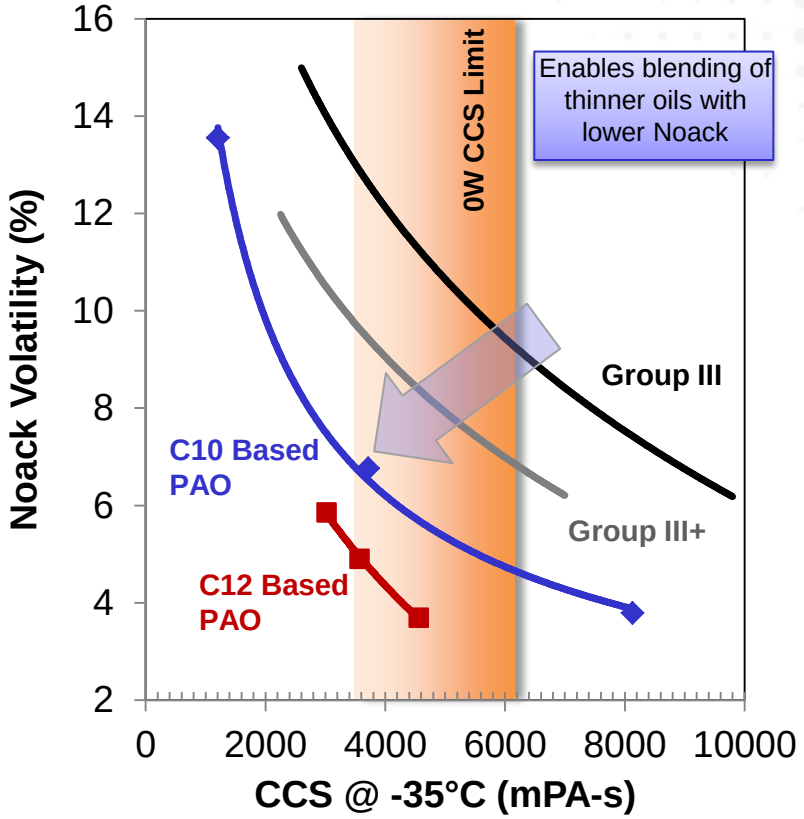
- Reducing the HTHS viscosity is a means to achieve improved fuel economy, maintaining a higher HTHS as the CCS viscosity decreases should provide a balance of fuel economy with wear and durability benefits



- Group III and Group III+ data taken from Flemming, J., *Lubricant Performance and Base Oil Supply: The Impact of Moving to Thinner Viscosity Grades*, 19th ICIS World Base Oils & Lubricants Conference, London 19th – 20th February, 2015.
- HTHS – High Temperature High Shear viscosity (ASTM D4683)
- CCS – Cold Cranking Simulator viscosity (ASTM D5293)

Volatility 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)



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Synfluid® PAO 6 vs. Synfluid® PAO 5 & PAO 6 HVI

Property	Synfluid® PAO 5	Synfluid® PAO 6 HVI	Synfluid® PAO 6
Kinematic Viscosity, cSt @ 100°C	5.1	5.9	5.9
Kinematic Viscosity, cSt @ 40°C	24.6	29.1	30.5
Kinematic Viscosity, cSt @ -40°C	4844	7000	7674
CCS, cP @-35°C	3018	3571	3715
Viscosity Index	143	150	138
Pour Point, °C	-47	-44	-63
Flash Point (COC), °C	246	249	244
Fire Point (COC), °C	278	291	274
Volatility, Noack, wt %	5.5	4.9	6.6
Specific Gravity, 15.6°/15.6°C	0.8244	0.8256	0.8277
Total Acid Number	<0.03	<0.03	<0.03
Bromine Index	<200	<200	<200
Odor	No Foreign Odor	No Foreign Odor	No foreign Odor
Appearance	Clear and Bright	Clear and Bright	Clear and Bright
Color, Pt-Co	0	0	0

- -40 °C Kinematic Viscosity, viscosity index, CCS & Noack Volatility are superior for PAO 6 HVI and PAO 5

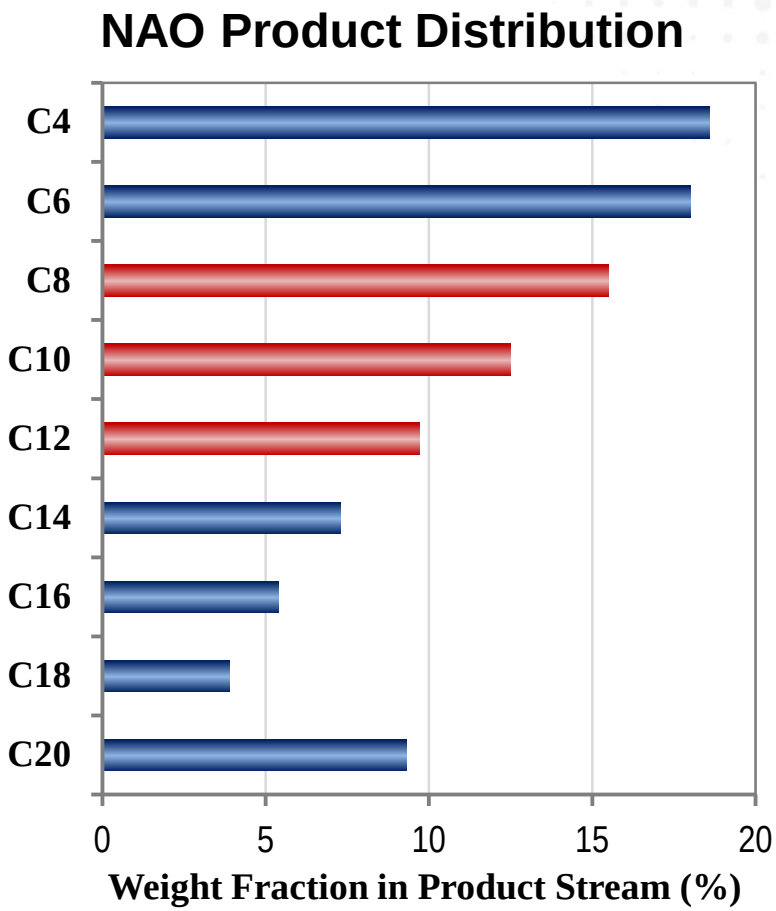
Synfluid® PAO 8 vs. Synfluid® PAO 7 & PAO 8 HVI

Property	Synfluid® PAO 7	Synfluid® PAO 8 HVI	Synfluid® PAO 8
Kinematic Viscosity, cSt @ 100°C	7.0	7.9	7.8
Kinematic Viscosity, cSt @ 40°C	38.3	44.1	46.9
Kinematic Viscosity, cSt @ -40°C	10,543	-	-
CCS, cP @-35°C	4558	7022	8126
Viscosity Index	146	153	135
Pour Point, °C	-44	-37	-55
Flash Point (COC), °C	263	267	263
Fire Point (COC), °C	294	300	292
Volatility, Noack, wt %	3.6	3.3	3.6
Specific Gravity, 15.6°/15.6°C	0.8305	0.8328	0.8322
Total Acid Number	<0.03	<0.03	<0.03
Bromine Index	<200	<200	<200
Odor	No Foreign Odor	No Foreign Odor	No foreign Odor
Appearance	Clear and Bright	Clear and Bright	Clear and Bright
Color, Pt-Co	0	0	0

- 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



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!

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