Developing basestocks to meet automotive regulations for lower emissions and improved economy

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Improved polyalphaolefin (PAO) base stocks designed to address the market needs of improved fuel economy and energy efficiency offer lower viscosity and volatility than conventional PAO and Group III base stocks.

Introduction

Over the past 30 years, polyalphaolefin (PAO) base stocks have been used extensively in automotive lubricants. These applications include engine oils, transmission fluids, and driveline fluids for passenger and heavy-duty vehicles.

PAO base stocks are synthetic molecules that resemble the hydrocarbon structure found in mineral oils. But PAO base stocks also offer high viscosity index, excellent low-temperature flow and pour-point characteristics, and good thermal and oxidation stability compared to mineral oils. The lack of lighter hydrocarbons lowers their volatility and raises their flashpoint.

New challenges in the automotive industry have arisen from the global trends toward lower emissions, improved energy efficiency, greater fuel economy, and electric vehicles (EVs). These challenges have highlighted the need to go beyond conventional PAO technology.

Stricter emissions standards are driving the need for improved fuel efficiency

Over the past decade, the most dominant global trend in the automotive industry has been fuel economy. The trends favoring reduced CO_2 emissions and improved fuel economy will only become more impactful as new and more stringent government policies and regulations are proposed and implemented.

Since 1997, there has been a 20-fold increase in global climate change laws, with more than 1,200 relevant policies across 164 countries.[1] Many of these regulations are focused on reducing CO_2 emissions and increasing the fuel economy of passenger vehicles.

In 2021, the European Union proposed a CO_2 emission reduction target for new passenger vehicles. The proposal would cut emissions 55% by 2030 and 100% by 2050 from 2021 levels. These new regulations would speed up the adoption of zero-emission EVs in the market.[2] Likewise, the U.S. Environmental Protection Agency has proposed strengthening standards for cars and light trucks. The plan would increase efficiency by 10% in 2023, followed by a 5% increase each year from 2024 through 2026.[3]

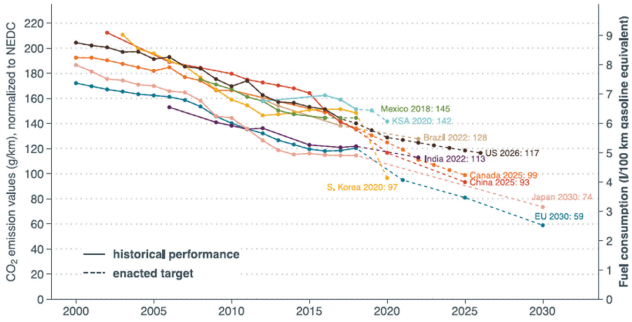
[1] "Mapped: Climate change laws around the world," Carbon Brief, 06-Aug-2018. [Online]. Available: https://www.carbonbrief.org/mapped-climate-change-laws-around-world. [Accessed: 12-Dec-2021].
[2] "CO_2 emission performance standards for cars and Vans," Climate Action. [Online]. Available: https://ec.europa.eu/clima/eu-action/european-green-deal/delivering-european-green-deal/co2-emission-performance-standards-cars-and-vans_en. [Accessed: 12-Dec-2021].
[3] EPA. [Online]. Available: https://www.epa.gov/regulations-emissions-vehicles-and-engines/proposed-rule-revise-existing-national-ghg-emissions. [Accessed: 12-Dec-2021].

Further to this, in 2022, India is set to put in place stricter standards for passenger vehicle fuel efficiency. These new standards will set the efficiency targets for new cars at 113 grams of CO_2 per kilometer.[4]

To comply with these new standards, car manufacturers are under pressure to improve the fuel economy of their vehicles. If they fail to meet these new targets, manufacturers in certain regions face significant fines and penalties that could amount to billions of dollars each year.

Regulations limiting CO_2 emissions have become a challenge and opportunity for lubricant formulators and car manufacturers alike. As the challenge ramps up, PAO technology will remain an important and cost-effective solution for increasing fuel economy in passenger vehicles.

Passenger car CO_2 emission and fuel consumption values, normalised to NEDC



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Details at www.theicct.org/chart-library-passenger-vehicle-fuel-economy

EV batteries and e-motors present new cooling challenges

Vehicles powered by internal combustion engines are not expected to disappear anytime soon. But increasingly stringent emissions regulations and supportive policies have expanded the EV market worldwide. In 2020, ten million EVs were on the road, and EV sales were nearly 5% of the total car sales worldwide.[5]

EV hardware is also changing from designs based on separate componentry to integrated e-modules. This shift provides an opportunity to move from multiple fluids to a single-fluid solution that can lubricate and cool these modules. This single-fluid solution must also show highly desirable electrical properties. Conventional PAOs and mineral-oil base stocks are not as suitable for heat transfer fluids and multipurpose fluids in such EV applications as these new generation of PAOs.

EVs have posed new challenges and requirements. The batteries and e-motors need adequate cooling to ensure safety and optimal performance, and, therefore, thermal management has become a major challenge. While indirect liquid cooling (typically using water/glycol) has been an effective method, this process leads to efficiency loss and reduces cooling performance. In contrast, direct cooling can offer a more efficient alternative. But direct cooling requires fluids with a different set of properties. Material compatibility and desirable electrical properties with long life are critical parameters that can provide significant challenges for e-fluid formulation using conventional base stocks.

Developing PAO basestocks

To help improve fuel economy and energy efficiency, formulators are seeking to develop lower viscosity oils without compromising on performance. The technical requirements of these lower viscosity oils are difficult to achieve with conventional PAO technologies. Formulators need new base stocks to meet rising fuel economy targets. Base stock suppliers are responding by developing new base stocks to help formulate low-viscosity oils.

Improved low viscosity, low volatility (LVLV) PAO base stocks could meet the need to help formulators rise to the challenge of higher fuel economy, energy efficiency, and durability expectations within the automotive industry. These base stocks offer lower viscosity, lower volatility, and higher oxidation resistance than conventional PAOs and mineral oil base stocks.

These new LVLV PAO base stocks also exhibit lower traction coefficient, leading to improved energy efficiency and potentially extending driving range, making them suited for low-viscosity EV driveline fluids.

[4] *"India: Light-duty: Fuel consumption," Transport Policy. [Online]. Available: https://www.transportpolicy.net/standard/india-light-duty-fuel-consumption/. [Accessed: 12-Dec-2021].*
[5] *IEA, "Policies to promote electric vehicle deployment – Global EV outlook 2021 – analysis," IEA. [Online]. Available: https://www.iea.org/reports/global-ev-outlook-2021/policies-to-promote-electric-vehicle-deployment. [Accessed: 12-Dec-2021].*

Continued on page 16

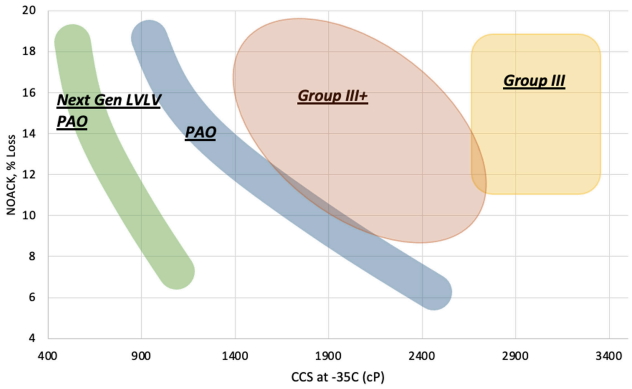
Continued from page 15

Low volatility for reduced oil consumption

Improved LVLV PAO base stocks have been designed to minimise oil volatility by carefully selecting and processing raw materials. Low volatility helps lower oil consumption while reducing CO_2 emissions and extending drain intervals.

New LVLV PAO base stocks have demonstrated lower volatility at high temperatures than conventional PAO and mineral-based Group I, II, and III base stocks. In Noack volatility testing, an improved LVLV PAO base stock with a KV100 of 3.5 cSt lost just 11.6% of its weight. This was lower than that of conventional PAO base stocks and Group III and III+ base stocks with a KV100 of ~4 cSt, which had weight losses between 12.6% and 17% and 11.9% and 40.7%, respectively.

Low Viscosity Basestocks - NOACK vs CCS at -35C



Excellent low-temperature properties for optimal performance

Fluid temperature stability is important to the performance of engine oils and determines their optimal operating temperature range. At low temperatures, fluid viscosity increases and reaches the pour point, and this is where it no longer flows and becomes unusable for specific applications. An improved LVLV PAO base stock has a pour point of -78°C, lower than conventional PAOs and Group III/III+ mineral oils, which have pour points ranging from -65 to -66°C and -18 to -33°C, respectively.

Cold-Crank simulator (CSS) test simulates oil viscosity in crankshaft bearings during cold temperature start-up. When compared to conventional PAO base stocks and Group III/III+ mineral oils, a new LVLV PAO base stock has the lowest viscosity with 790 centipoises in a CCS test at -35°C. In both of these tests, the new LVLV PAO base stock shows excellent low-temperature properties.

Improved oxidative stability for engine cleanliness and longer drain intervals

Oxidation occurs when a lubricant combines with oxygen and is responsible for several lubricant problems, including viscosity increase and the formation of varnish, sludge, and sediment. With this in mind, oil with high oxidative stability is desirable as it supports engine cleanliness and longer drain intervals.

In our tests, the improved LVLV PAO base stock demonstrated superior oxidative stability and had lower viscosity and Total Acid Number change after 192 hours at 170°C than conventional PAO and Group III/III+ mineral base stocks. And in an oxidation test, the new base stock lasted more than twice as long as any other base stock.

Enhanced lubricity and traction for enhanced energy efficiency

Engine oils and EV lubricants are designed to reduce the amount of friction between surfaces. This feature can increase energy efficiency and potentially extend the driving range in EVs or lead to less fuel consumption in an Internal Combustion Engine (ICE).

In Mini-Traction Machine (MTM) tests that measure the friction coefficient property of lubricated contacts, improved LVLV PAO base stock demonstrated significantly lower friction coefficient and torque loss compared to conventional PAOs and Group II+/III+ mineral oils. These enhanced lubricity and traction characteristics can lead to improved fuel economy and energy efficiency.

Improved flash point for safety

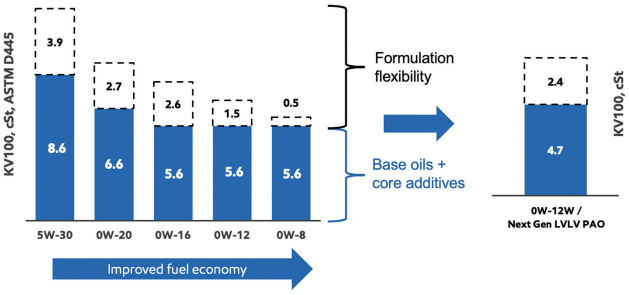
The flash point is the lowest temperature at which an ignition source causes the vapors of a lubricant to ignite under specified conditions. The flash point is typically 225°C for mineral oils and helps indicate the safety hazards concerning fire and explosion. ASTM D92 and D93 cover the flash point and the slightly higher fire point.

When tested with the ASTM D92 test, improved LVLV PAO base stock had a flash point of 234°C, higher than the flash point ranges of conventional PAOs and Group III/III+ mineral oils, which had flash points ranges of 220 to 224°C and 201 to 232°C, respectively.

Formulation flexibility

The trend toward lower-viscosity grades has improved energy efficiency for the automotive industry, and it has also created some challenges for formulators. PAO base oils have been challenging for formulators due to limited additive solubility. As the viscosity grade lowers, a "formulation squeeze" is created, offering less opportunity for performance additives.

Thanks to its unique chemical structure, the improved LVLV PAO base stocks provide formulators with the opportunity for more formulation flexibility than existing low-viscosity base stocks. Specifically, formulations containing new LVLV PAO base stocks do not require the addition of high-volatility fluids. This allows formulators to include various additives—such as viscosity modifiers for improved fuel economy, detergents or dispersants for cleaner engines, and sulfur and phosphorus for better wear protection—without compromising performance.



Improved PAO base stocks deliver step out performance

The improved LVLV PAO base stocks leverage unique PAO structures that provide the quality-enhancing properties described in the previous section. Those properties, ultimately, are designed to translate to enhanced performance in terms of fuel economy, energy efficiency, and durability.

LVLV PAOs provide excellent fuel economy performance

Fuel economy is measured under controlled conditions using a series of manufacturers tests. Based on tests that ExxonMobil has performed, lubricant formulations made with new LVLV PAO base stocks have continuously outperformed alternatives in fuel economy tests.

For example, using 0W-12 engine oil in Volkswagen fuel economy test PV1496, an improved LVLV PAO base stock demonstrated superior fuel economy compared against a Group III+ mineral oil and a conventional PAO base stock. In another comparison based on a Toyota 0W-8 test, the new base stock showed enhanced fuel economy versus formulations using low-viscosity esters.

These examples illustrate the opportunity for formulators to leverage new LVLV PAO base stocks to improve fuel economy for car manufacturers.

Our studies have shown that a LVLV PAO base stock with lower viscosity and enhanced thermal properties can provide excellent heat transfer properties in automotive and other cooling applications like data centers. Lower viscosity can improve thermal efficiency as it improves heat transfer and reduces pumping resistance within the system.

In direct cooling, the heat transfer fluid is in direct contact with components like the e-motor's windings, electronic, and battery components. This provides a unique advantage by creating a more uniform thermal management environment compared to indirect cooling where the heat transfer fluid, typically water-glycol, is in intermittent contact with system components creating a less uniformly cooled environment. Desirable electrical properties are essential to enabling direct cooling, and that's where LVLV PAO base stocks provide an advantage compared to water-glycol.

The battery is another component of the EV that may require advanced thermal management with different operating conditions (e.g., temperature) compared with e-motors and drive-units. Air, water-glycol, dielectric (e.g., hydrocarbon) fluids, phase-change material, and refrigerants are different options for battery thermal management. LVLV PAO base stocks can enable direct cooling that offers more uniform thermal management distribution in the system and can improve safety, thermal management, performance, and life of the battery in EVs.

Energy efficiency and thermal management for today and tomorrow's EVs

For EVs, new LVLV PAO base stocks offer a single-fluid solution that lubricates, cools, and shows other benefits like enhanced oxidative stability and desirable electrical properties for today's integrated e-modules.

Continued on page 18

Continued from page 17

The high thermal efficiency and desirable dielectric properties throughout the life of a fluid makes improved LVLV PAO base stocks well suited for direct cooling applications. This improves thermal management of e-motor and electronics in EV and can help with immersion cooling for batteries. With having lower viscosity, they can also provide enhanced thermal management in the system compared to conventional PAO or Gr II/III base stocks. LVLV PAO base stocks also have excellent oxidative stability, which can help with the lifelong operation of the oil.

One of the most important characteristics of next-generation LVLV PAO base stocks is providing lower traction coefficient/torque loss, resulting in improved energy efficiency, and extending the range of EVs.

Conclusion

Over the last decade, the demand for PAO base stocks has been growing due to extended drain intervals, better temperature performance, increased durability, and improved energy efficiency that they offer. But to meet increasingly demanding OEM specifications, engine oils and EV driveline fluids are evolving to lower viscosity while still delivering the same performance levels and wear protection as their predecessors.

As formulators develop new lubricants to meet these demands and reduce emissions, improved LVLV PAO base stocks offer several distinct advantages. Through an outstanding balance of low viscosity and volatility, the new LVLV PAO base stocks help deliver step-out performance, including fuel economy improvements for lower emissions, energy efficiency for extended electric vehicle range and enhanced thermal management for e-motor and electronics. LVLV PAO base stocks also offer superior oxidative stability, which can help with improving the life of the automotive lubricant.

Improved LVLV PAO base stocks with excellent balance of low viscosity-low volatility, superior oxidative stability, improved energy efficiency and thermal management will certainly help formulators continue to deliver innovative lubricants and fluids for the ever-changing automotive market today and tomorrow.

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