White Paper

ExxonMobil

How Synthetic Base Oils can help create novel e-Mobility fluid formulations

Abstract. In the last decade, the automotive industry has seen rapid changes looking to improve fuel economy and energy efficiency in mechanical systems. These changes present new requirements and specifications for automotive lubricants. Rapid development of Hybrid and Electric Vehicles (EV) with new operating conditions, along with using lower viscosity lubricants to improve energy efficiency, brings new challenges for lubricant and fluid developments, particularly for driveline fluids. Base oil properties have become more critical as lubricants shift to ultra-low viscosity, where balance of the lowered viscosity and desirable physical properties becomes challenging.

In this study, different blends have been developed using synthetic base oils, Gr IV and Gr V, in comparison with mineral base oils, Gr II/+ and Gr III/+. Different tribological and physiological properties of blends have been investigated. Synthetic blends have shown superior properties which can be critical for next generation EV lubricants. Synthetic blends have shown improved oxidative stability which can help enable longer drain intervals and desirable electrical properties over the life of lubricant. Excellent lower traction results demonstrated by using synthetic base oils can result in improved fuel economy and/or energy efficiency and potentially extend the EV range. Other testing has also been conducted to evaluate lubricant properties for EV applications.

Technology Advancement

The automotive industry has seen rapid changes over the last decade in order to improve energy efficiency and durability while also reducing CO_2 emissions. Fig. 1 shows the transition in the automotive industry from reducing vehicle weight to developing full electric vehicles.

Lubricant has been one of the key enablers for technology enhancement and improving energy efficiency in the automotive industry [1]. Base oil is the major part of lubricant formulations which plays an essential role on lubricant performance, particularly as the lubricant goes to lower viscosities to improve energy efficiency. Base oils can be either mineral or synthetic. Mineral base oils are a complex blend of hydrocarbons varying in structure and properties, with processing aimed at removing or modifying undesirable components. Synthetic base oils are synthetized based on controlled feedstock using known chemistry to produce products with relatively uniform structures and tailored properties.

As demonstrated throughout this work, synthetic base oils show a number of performance benefits compared to mineral base oils. Synthetic base oils have better cold temperature properties and lower traction which can improve energy efficiency in the e-module system (gearbox, e-motor, bearings, clutch), thus extending vehicle range. When compared to mineral base oils, synthetic base oils can also contribute to improved oxidation stability, and our work in this area also suggests improved thermal conductivity, enhanced tribological performance under elastohydrodynamic lubrication (EHL) conditions, and desirable dielectric properties throughout the life of the electric fluid. Overall, EV driveline fluid development presents new challenges, and synthetic base oils can provide an optimal balance of lubricant, thermal, and electrical properties for longer lasting fluid in EV applications.

FIGURE 1

Technology advancement in the automotive industry.

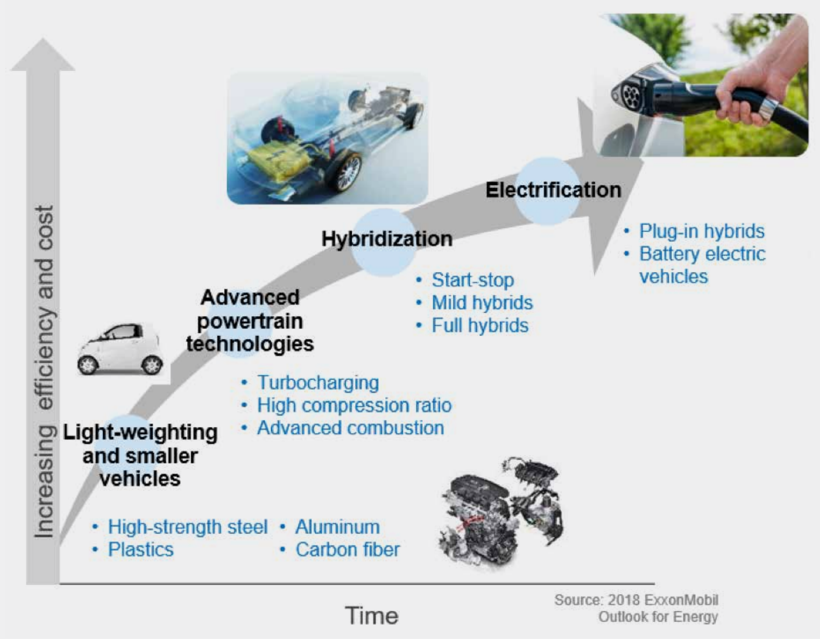
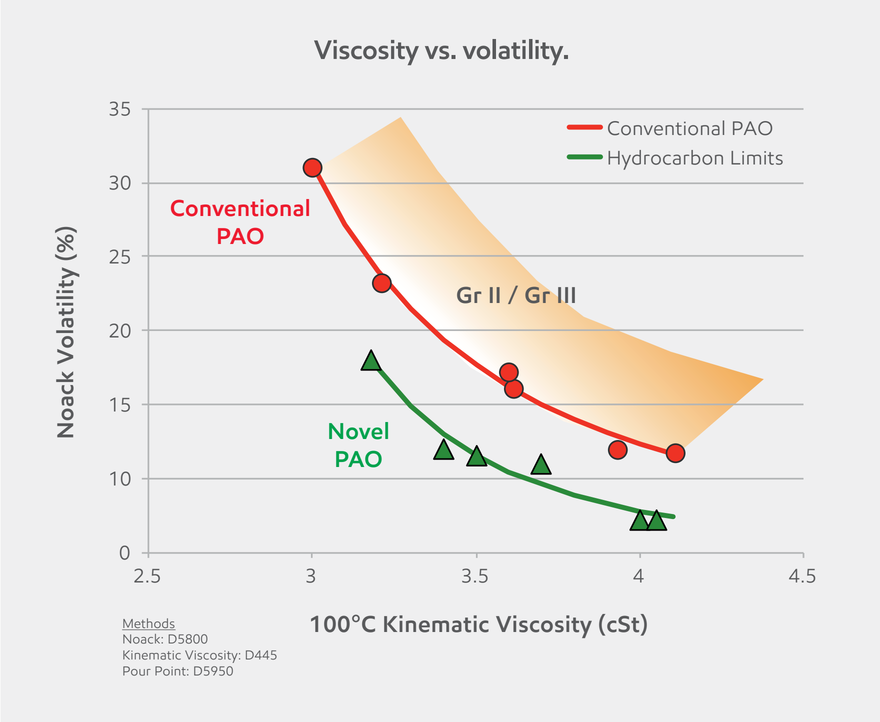


FIGURE 2



ExxonMobil Chemical Company has been a pioneer in synthetic fluid technology and is committed to bring new solutions and products to address its customers' increasingly challenging demands. Fig. 2. depicts a novel synthetic polyalphaolefin (PAO) in comparison to conventional PAO and mineral base oils which can provide superior performance and durability for EV driveline fluids. Novel synthetic PAOs can provide an excellent balance of low viscosity and low Noack volatility, which can deliver an advantage for e-module performance in EV applications as operating temperature tends to be higher than conventional drivelines.

Thermal Management

Conventionally in an e-module, one fluid is used for lubricating the gearbox, and another fluid, typically water/ethylene glycol (EG), is used for cooling the e-motor and electronics. Additionally, another lubricant, like grease, may being used for lubricating the e-module components (i.e. bearings) in the system.

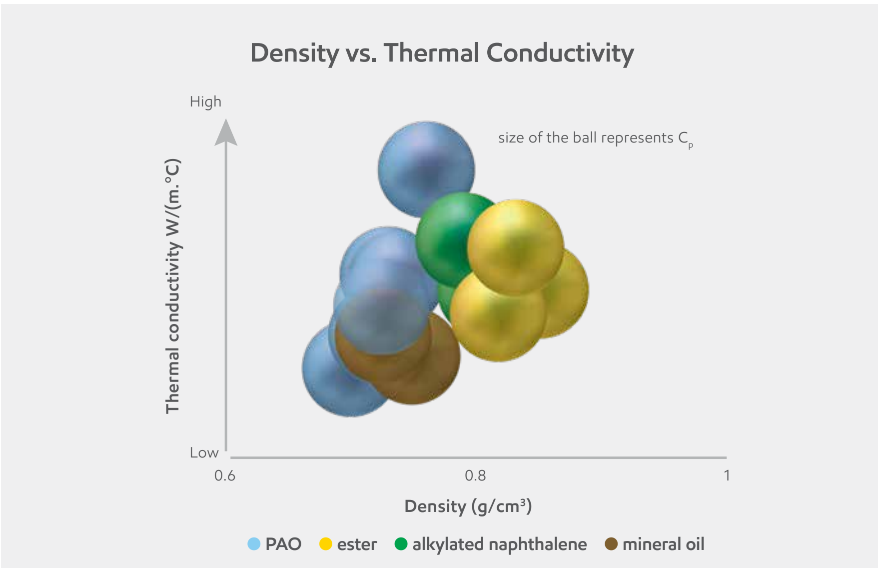
In recent years, automotive companies have shown interest towards a single fluid system, where the fluid used for lubricating the gearbox is also used to cool the e-module (i.e. e-motor and electronics) and lubricate its components (i.e. bearings). This method can provide a safer, lighter, and more efficient system. Oil has superior dielectric properties compared to water/EG and can thus be safer to operate. Using a single fluid can help enable more compact designs and reduce the weight of the system.

One of the key advantages of synthetic fluids like PAO, ester, and alkylated naphthalene is superior dielectric properties compared to water/EG. This enables direct cooling of the e-module and may help provide improved heat transfer efficiency compared to indirect cooling [2]. We are performing additional testing to understand the benefits of direct cooling using synthetic base oils not only in e-module systems, but also in EV battery systems.

Viscosity of the fluid plays a key role in pumping efficiency. Synthetic fluids like PAO offer a wider range of viscosity and can go to much lower viscosity (< 2 cSt, KV 100°C) compared to existing mineral base oils being used in driveline formulations. This suggests synthetic fluids with lower viscosity can provide higher pumping efficiency and potentially higher heat transfer efficiency in the system.

Fig. 3 shows synthetic base oils like PAO, ester, and alkylated naphthalene also typically have higher thermal conductivity than mineral base oils. Hence, synthetic base oils can improve heat transfer properties when cooling the e-modules in EV.

FIGURE 3



Oxidative Stability

Oxidative is an important parameter enabling lubricants to have a longer service life while maintaining wear protection characteristics. Oxidation can degrade the base oil, resulting in increased viscosity and acid formation, which in turn impacts the intended design properties of the fluid. In an integrated e-module where the e-motor is close to the gearbox, it is likely to have a higher operating temperature for the lubricant in the system. Because EV fluids experience higher operating temperatures and are designed to be fill-for-life, having superior oxidative stability throughout the life of the vehicle is critical to prevent potential damage to the e-module components. Synthetic base oils like PAO, ester, and alkylated naphthalene can provide superior oxidative stability compared to mineral base oils, thus providing durability advantages.

Our preliminary work suggests oxidative stability is also important to the stable electrical performance of the fluid throughout its service life. Fluid oxidation can negatively impact the electrical characteristics over time. We are performing additional research into how oxidation affects fluid performance in this area.

Fig. 4. shows a novel-PAO blend with excellent oxidative stability compared to the Gr II+/Gr III+ blend at the same viscosity using a similar additive package. In this work, the CEC L-48 method up to 384 hrs at 170°C has been used to evaluate oxidative stability. Results suggest the novel-PAO blend can provide longer lasting oxidative stability performance which translates into improved durability and thermal and electrical performance of EV driveline fluids.

Pressure-Temperature Viscosity Dependency

Viscosity of a lubricant is typically measured at ambient pressure in the laboratory. However, lubricants in mechanical components typically operate in the EHL regime (like bearings or gears) and can experience rapid and severe pressure increases (1-3 GPa pressure) [3].

Using a high-pressure viscometer apparatus developed by Professor Scott Bair at the Georgia Institute of Technology [4], we studied the pressure-temperature viscosity behavior of novel-PAO, conventional PAO, and Gr II+/III+ blends at pressures similar to EHL contact rather than only ambient pressures. Several studies during the last several decades have demonstrated the differences between different base oils or lubricants at high pressures and varying viscosity regimes [4-6].

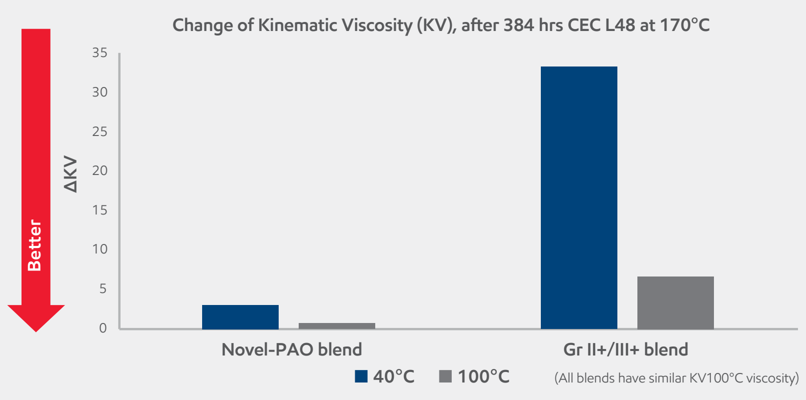
Fig 5. shows the pressure vs. viscosity relationship for both a novel-PAO blend and a Gr II+/III+ blend at 40°C (solid lines) and 100°C (dashed lines). At 100°C the blends behave similarly, but at 40°C the Gr II+/III+ blend shows an anomalous pressure-temperature viscosity response as indicated by the significant increase in viscosity at higher contact pressures. This suggests a possible phase transition of the blend at pressures similar to those experienced in EHL contact. Meanwhile, the novel-PAO blend demonstrates normal pressure-temperature viscosity behavior. Possible phase transition of Gr II/+ or Gr III/+ base oils and their blends may have unanticipated consequences in tribological contact [5]. We are currently conducting additional work to map out the envelope of this anomalous pressure-temperature viscosity response across a range of temperatures and pressures.

Energy Efficiency

Reducing CO_2 emissions and improving energy efficiency has been of high interest for automotive manufactures. Automotive lubricants, including EV driveline fluids, are key to achieving the highest energy efficiency in the system. In EVs higher energy efficiency in mechanical systems, like reduction gears, can enable extended range, which is highly valuable for automotive manufactures and consumers. Synthetic PAO and Gr V molecules can provide

FIGURE 4

Oxidative stability (CEC L48) novel-PAO blend vs. Gr II+/Gr III+ blend.



lower traction compared to mineral base oils. Lower traction can result in improved energy efficiency in mechanical systems.

Using the PCS mini traction machine (MTM), we compared the traction coefficient of novel-PAO, conventional PAO, and Gr II+/III+ blends at 30N load and 2 m/s speed across 0-70% slide-to-roll ratio (SRR). Fig 6. shows the novel-PAO blend having significantly lower traction than both the conventional PAO and Gr II+/III+ blends. The novel-PAO blend shows a 25% improvement in traction coefficient over the Gr II+/III+ blend. These results suggest higher energy efficiency for the novel-PAO blend compared to conventional PAO and mineral oil blends, which can result in longer vehicle range.

FIGURE 5

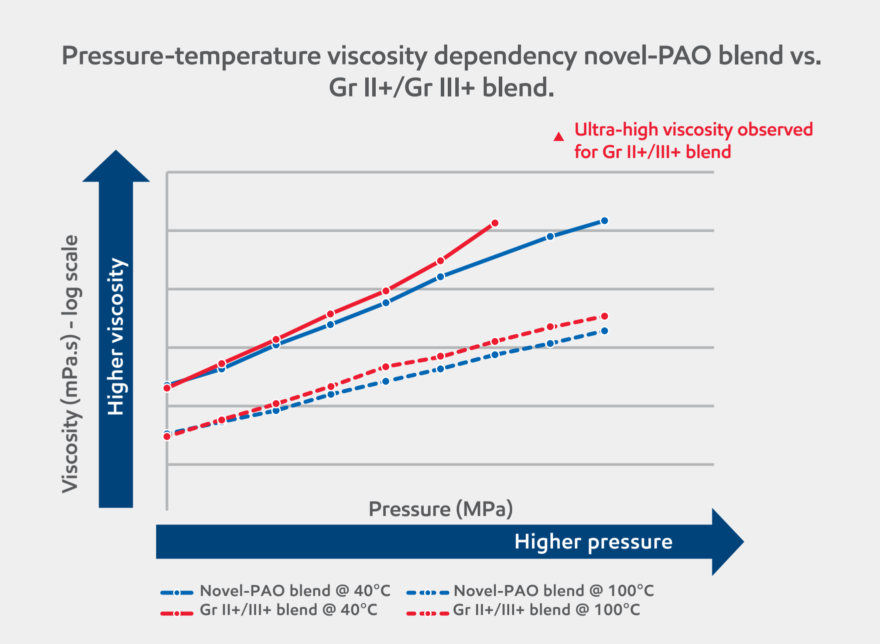
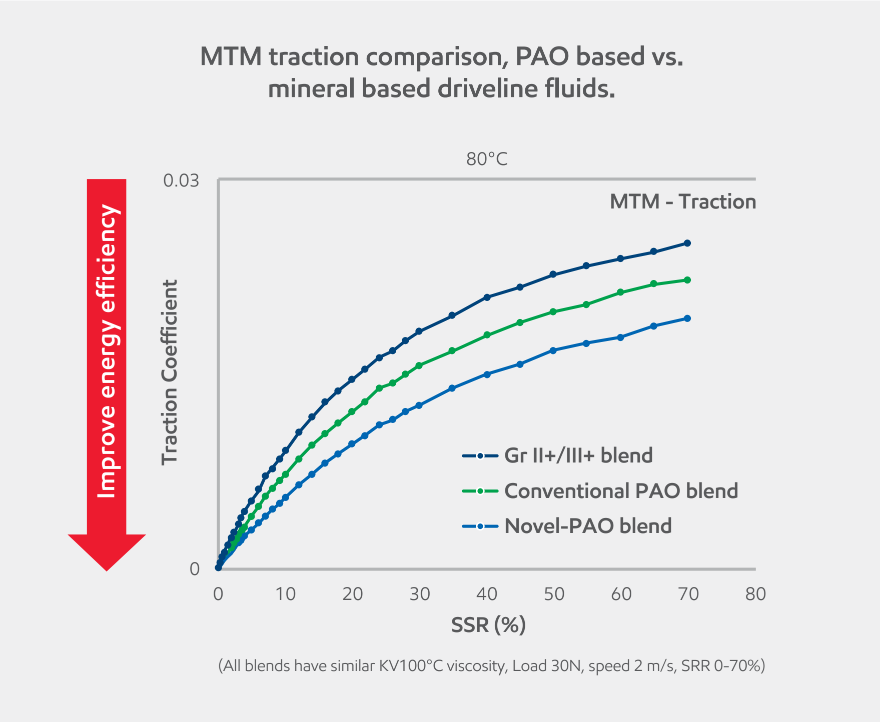


FIGURE 6



Conclusion

- E-modules, including gearboxes, e-motors, bearings, clutches, electrical components, and new materials, bring new challenges for EV fluids.
- Synthetic base oils, including the novel-PAO base oil, and their fully formulated blends show excellent thermal properties, oxidative stability, energy efficiency, film thickness, clutch performance, etc.
- High pressure-temperature viscosity testing suggests possible phase transition of Gr II/+ or Gr III/+ base oils and their blends, which could result in unanticipated consequences in mechanical systems like bearings and gears.
- Gr IV and Gr V synthetic base oils can help develop more efficient fluids for EV applications with superior properties for a safer, more efficient, and longer service life.
- ExxonMobil Chemical Company has been a leader in developing novel molecules for lubrication applications, and the work that is described here builds on this expertise and applies it to the emerging challenges of EV fluid formulations. Future research will further develop our understanding of the advantages of using synthetic base oils in these emerging applications.

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