Polyalkylene Glycols

How Different Polymer Architectures Influence Tribology Performance

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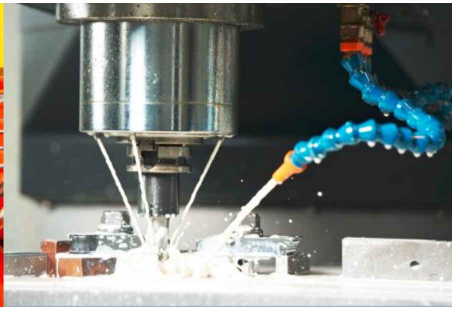
Objectives

- Show how different polymer architectures of known PAGs can influence rheology and tribology properties.

- Build on our knowledge of PAGs in relation to their rheology and tribology behavior and how an understanding can help us select PAGs with optimum friction control properties.



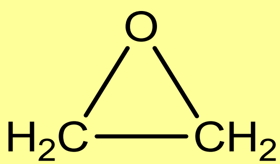



Contents

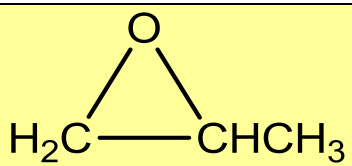
- Brief Overview of PAGs
- Chemistry - Polymer Design and Functionality
- EHD Traction Properties and Correlation with Polymer Chemistry
- High Pressure Viscosity Behavior – Pressure Viscosity Coefficients
- Correlating Alpha Values and Traction Coefficients
- Conclusions

Overview of PAG Chemistry

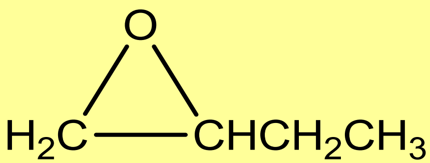
Three key oxide building blocks



Ethylene oxide

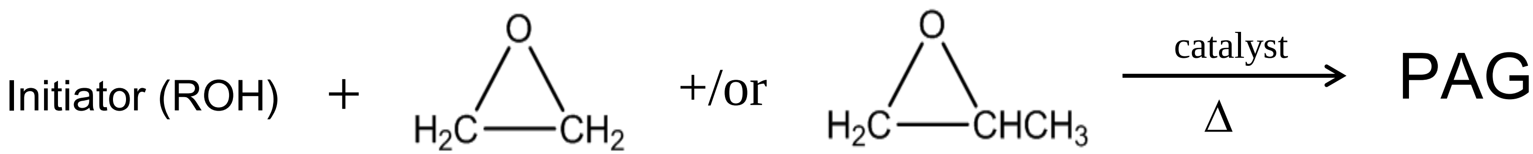


1,2-Propylene oxide



1,2-Butylene oxide

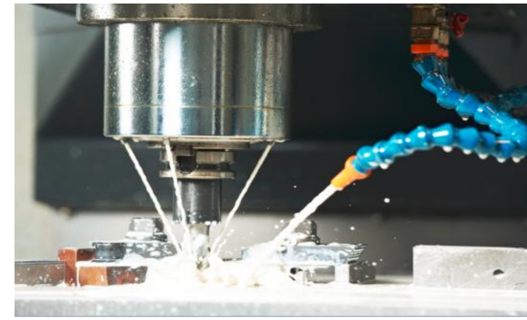
Traditional synthesis procedure



ethylene oxide (EO) propylene oxide (PO)

Initiator plays an important role in determining rheology and tribology behavior
Typically based on alcohols but amines, thiols and other initiators with labile hydrogen atoms can be used

Applications for PAGs



Established Applications of PAGs

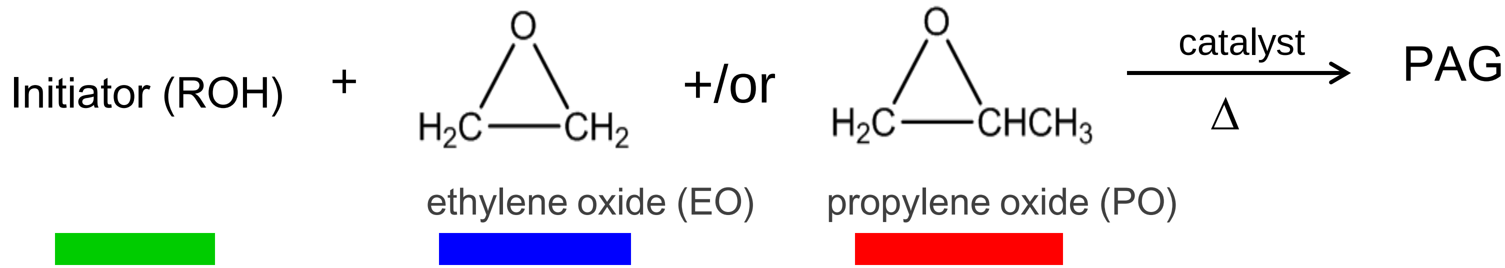
- Air Compressor Fluids
- Natural Gas Compressor Fluids
- Water Glycol Hydraulic Fluids
- Metalworking Fluids
- Quenchants
- Gear Oils

Recent New Applications for PAGs

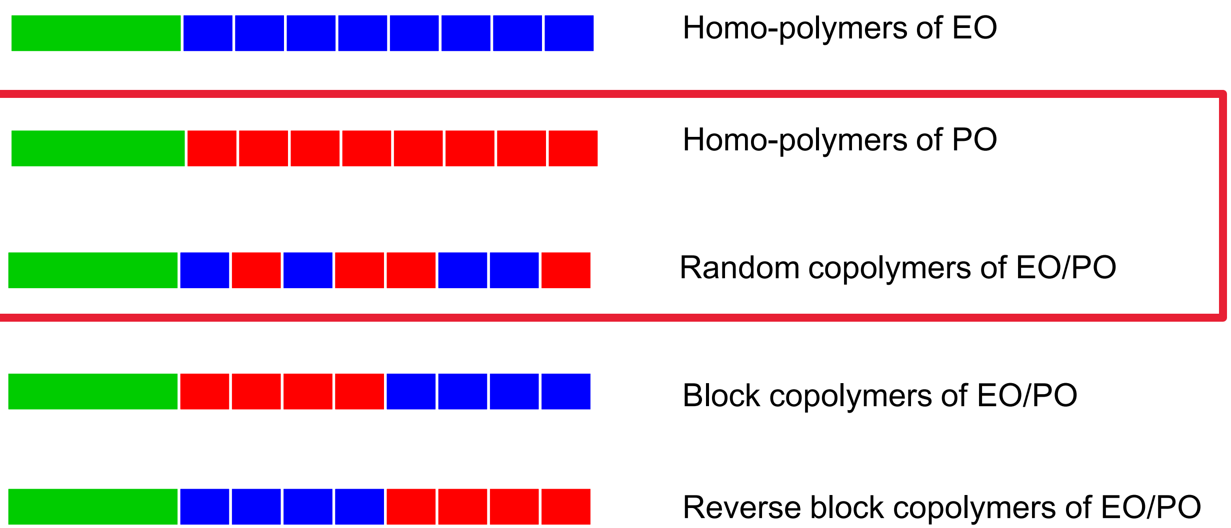
- Turbine Oils
- Wind Turbine Lubricants
- Non-Sheening Hydraulic Fluids

Conventional Polyalkylene Glycol Technology

Typical Synthesis Route to Polyalkylene Glycols



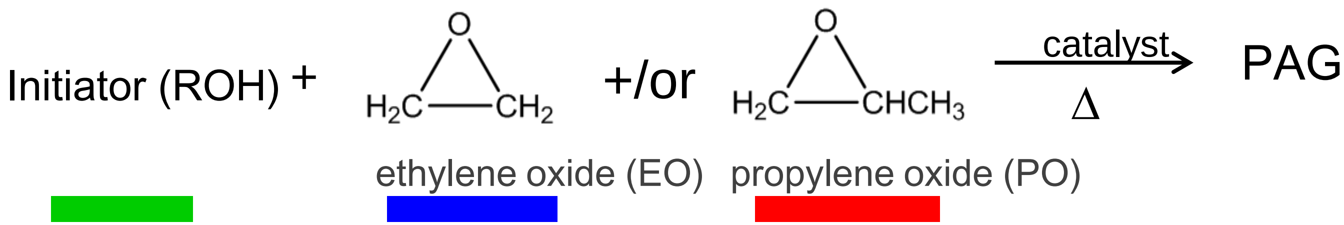
Types of PAGs by Chemical Family



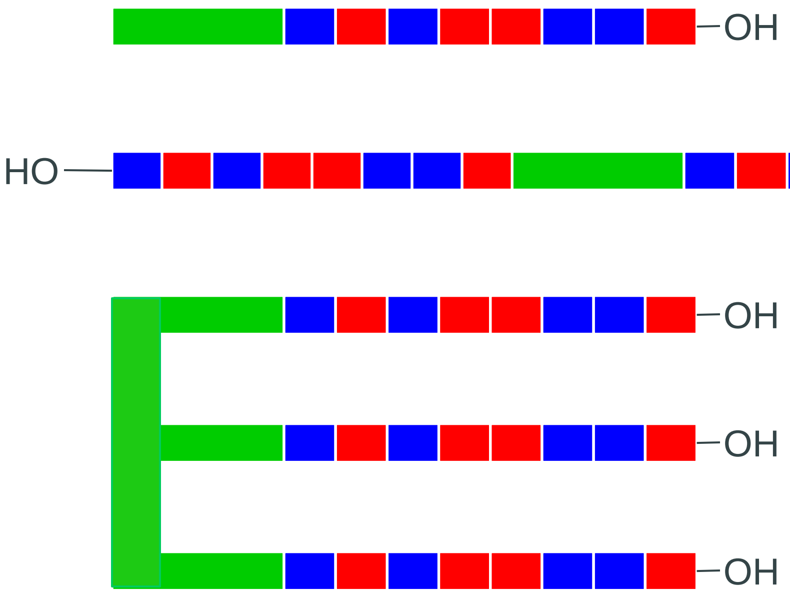
Most common PAG base stocks today

PAGs can be designed to a wide range of molecular weights, viscosities and functional performance

Monol, Diols, Triols – Different Architectures



Classical random co-polymers of EO/PO - Impact of Initiator on Polymer Architecture



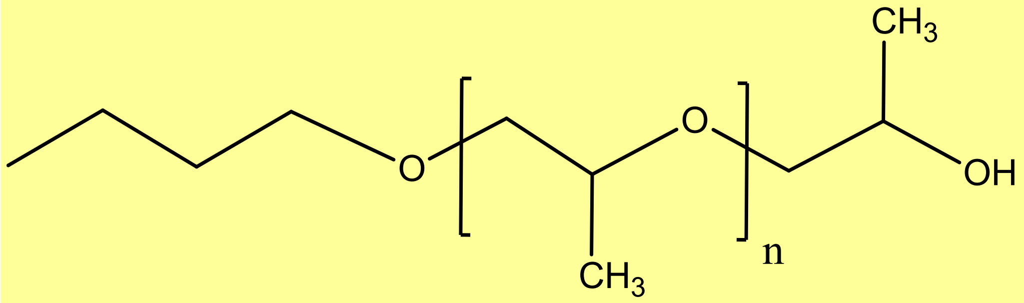
Monols (“Linear”)

Diols (“Linear”)

Triols (Branched)

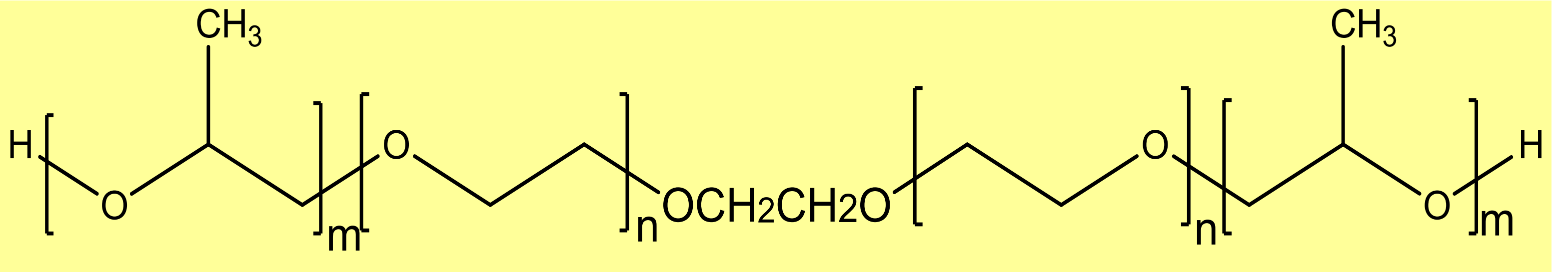
Examples of Common PAGs

Monol: PO Homo-polymer



Commonly used in hydraulic, compressor and gear oils

Diol: EO/PO Co-polymer

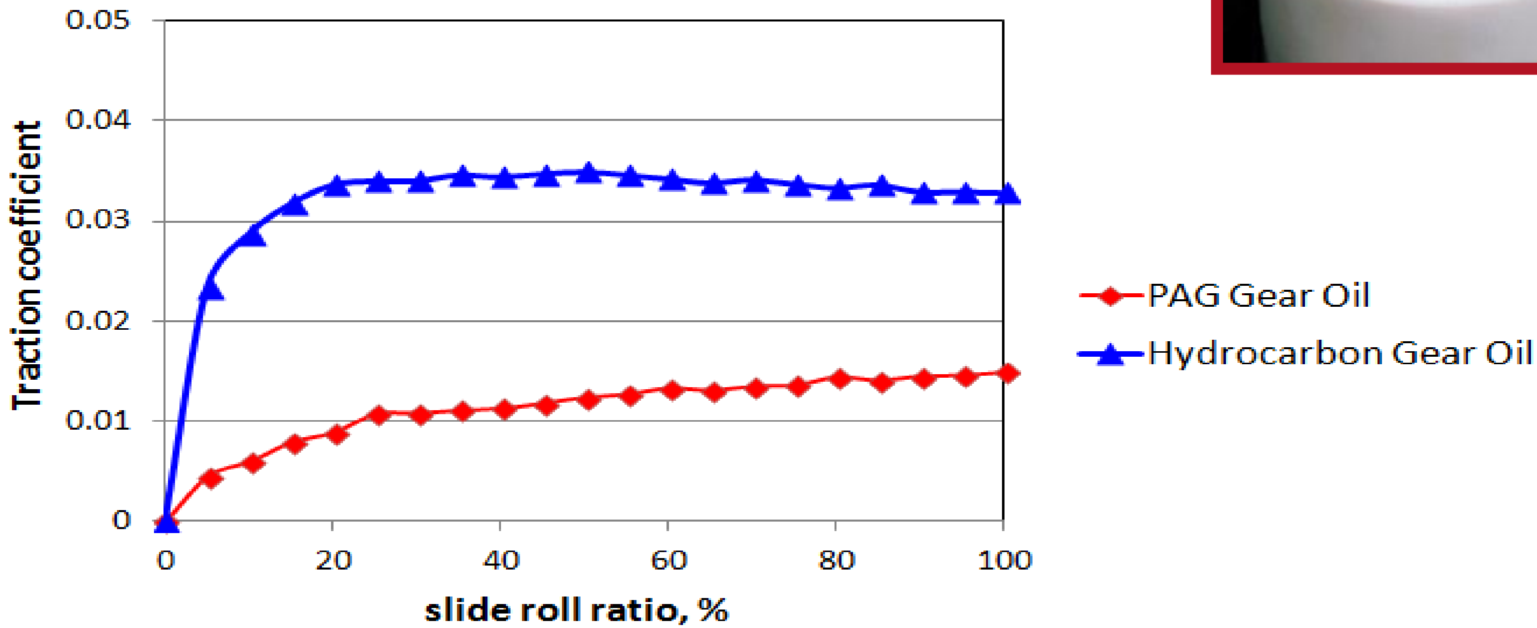


Commonly used in gear oils, compressors and water based lubricants

Preliminary Traction Measurements

Early experiments conducted 10 years ago using a Mini-Traction Machine on ISOVG-320 Gear Oils

Contact Pressure = 0.9GPa, Temp. 80ºC and speed 3 m/sec.
Steel ball on steel disc



Observed very low EHD traction values for the PAG product

Traction Measurement Experiments

Conditions

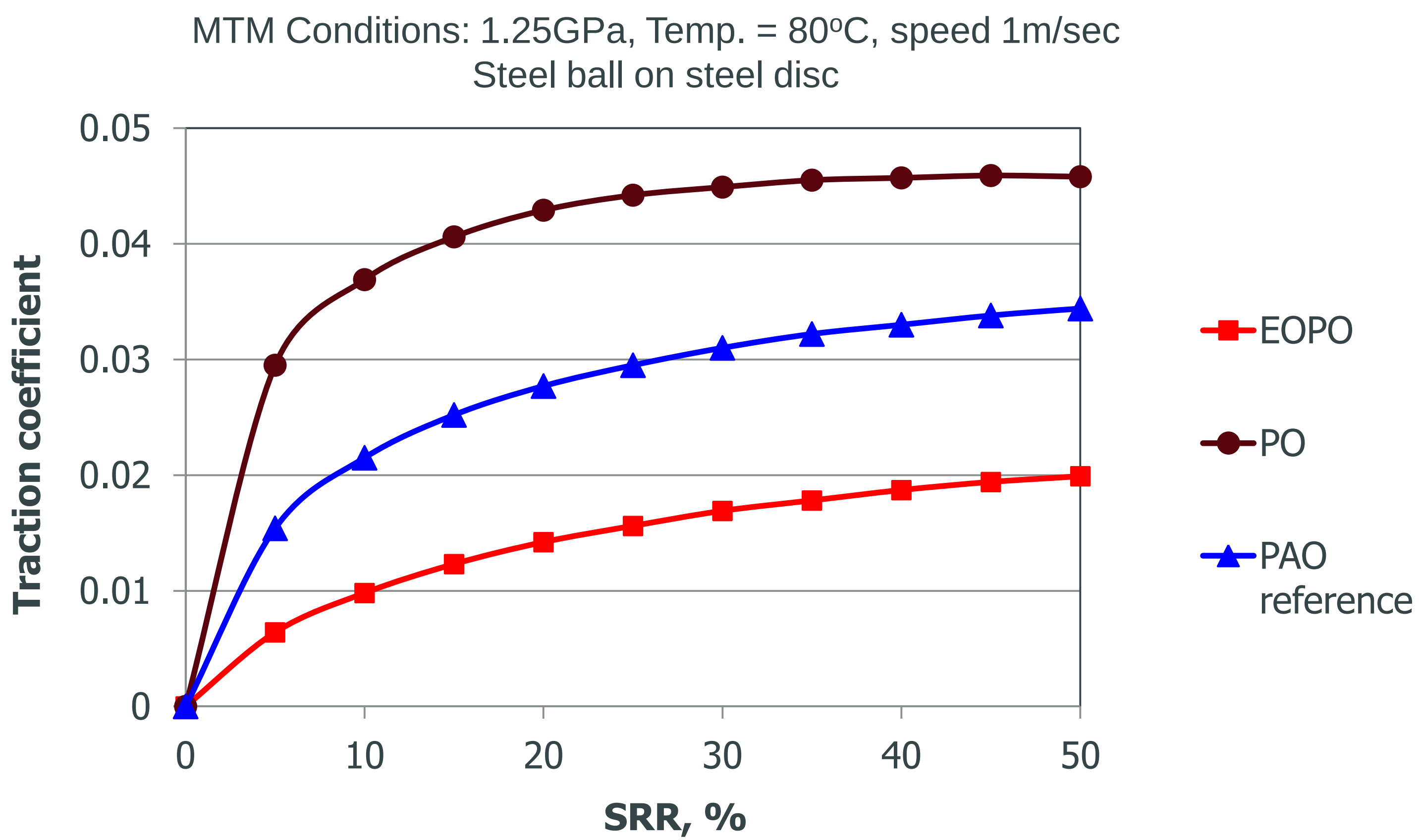
- Temperature = 80^{o}C
- Slide Roll Ratio (SRR) = 0-50%
- Contact pressure = 1.25GPa
- Speed = 1 m/sec

Objectives

a) Compare EO/PO copolymers versus PO Homo-polymers
b) Assess if polymer branching from the initiator impacts traction behavior
c) Develop some PAG design rules for controlling traction

PAO base oil was used as a reference throughout the study

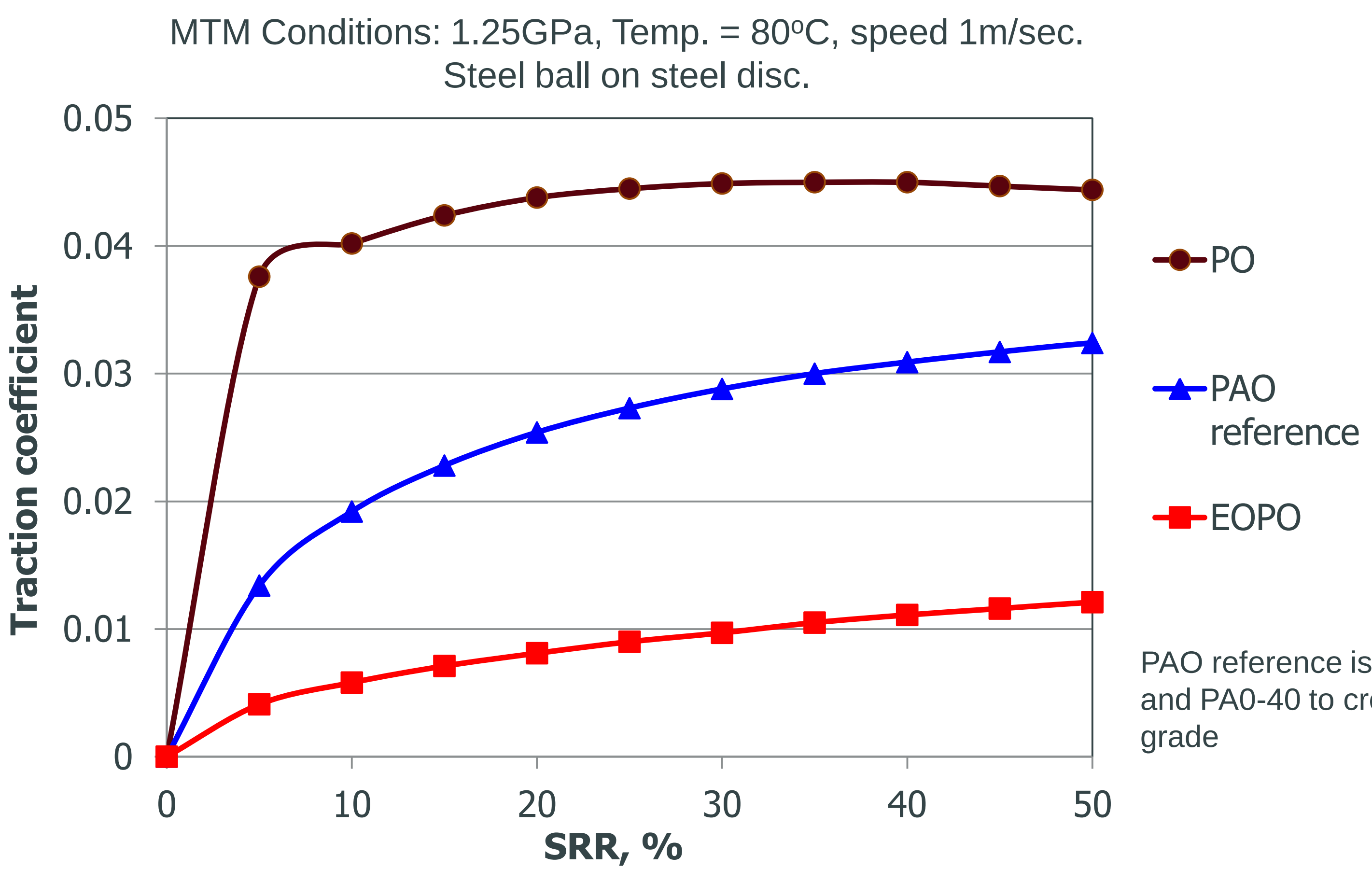
Fixed Monol Initiator & ISO-68 Base Oils



EO/PO PAG exhibits low traction values

Surprisingly the PO PAG exhibits much higher traction values

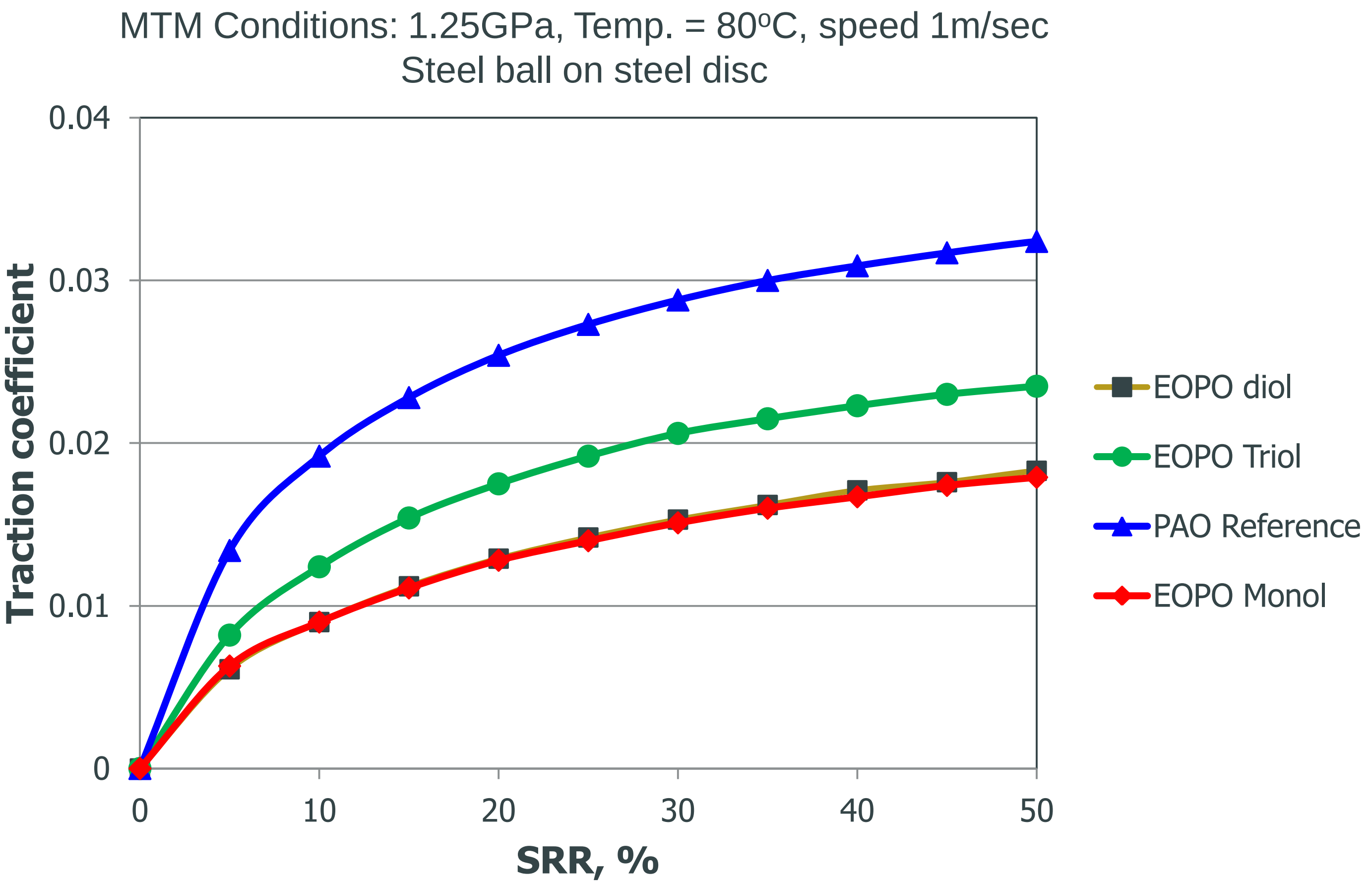
Fixed Diol Initiator & ISO-320 Base Oils



PAO reference is a blend of PAO-6 and PA0-40 to create an ISO-320 grade

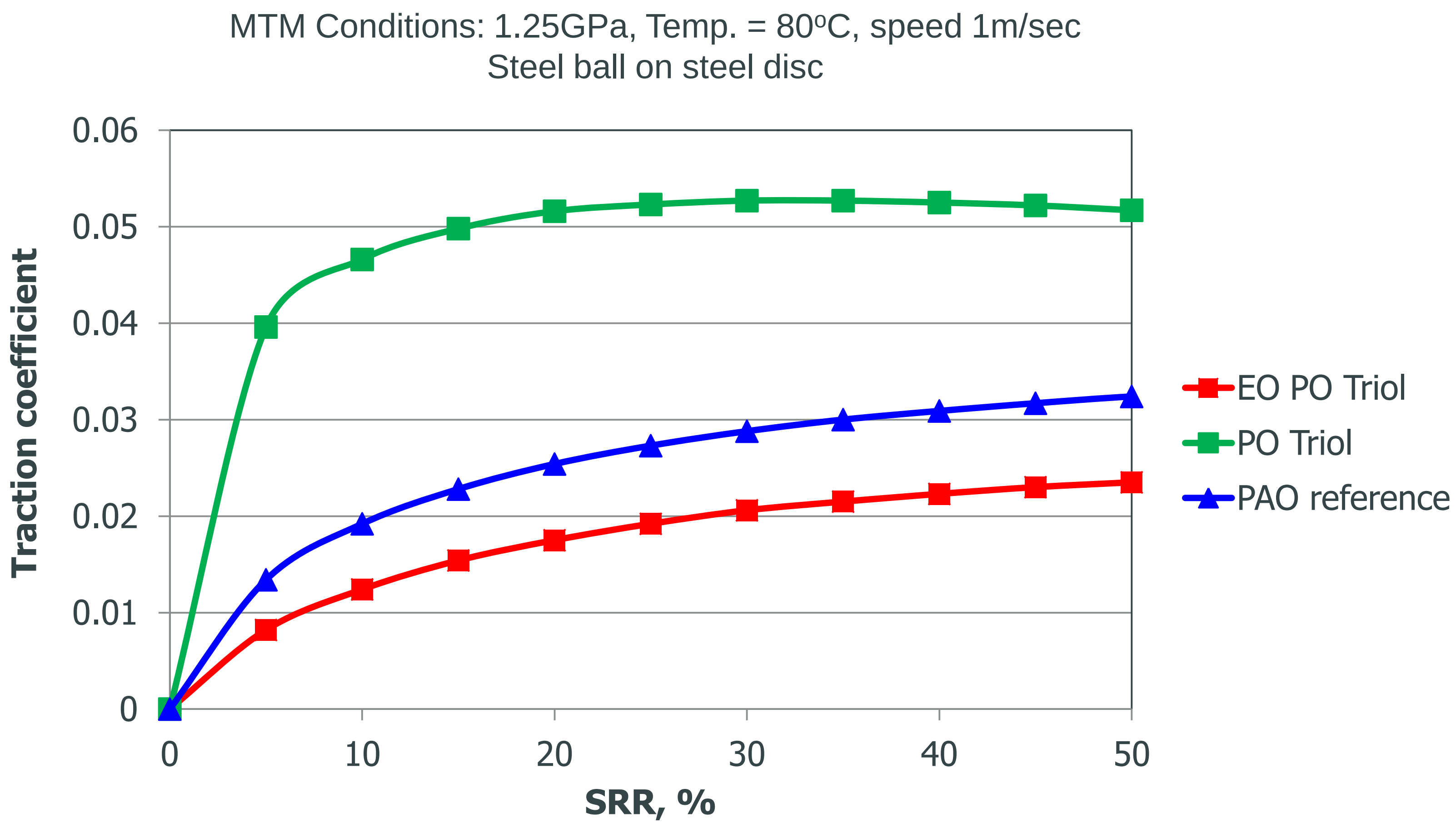
EO/PO PAG exhibits low traction values
PO PAG exhibits much higher traction values

Effect of Initiator – Fixed EO/PO ratio and ISO-150 PAGs



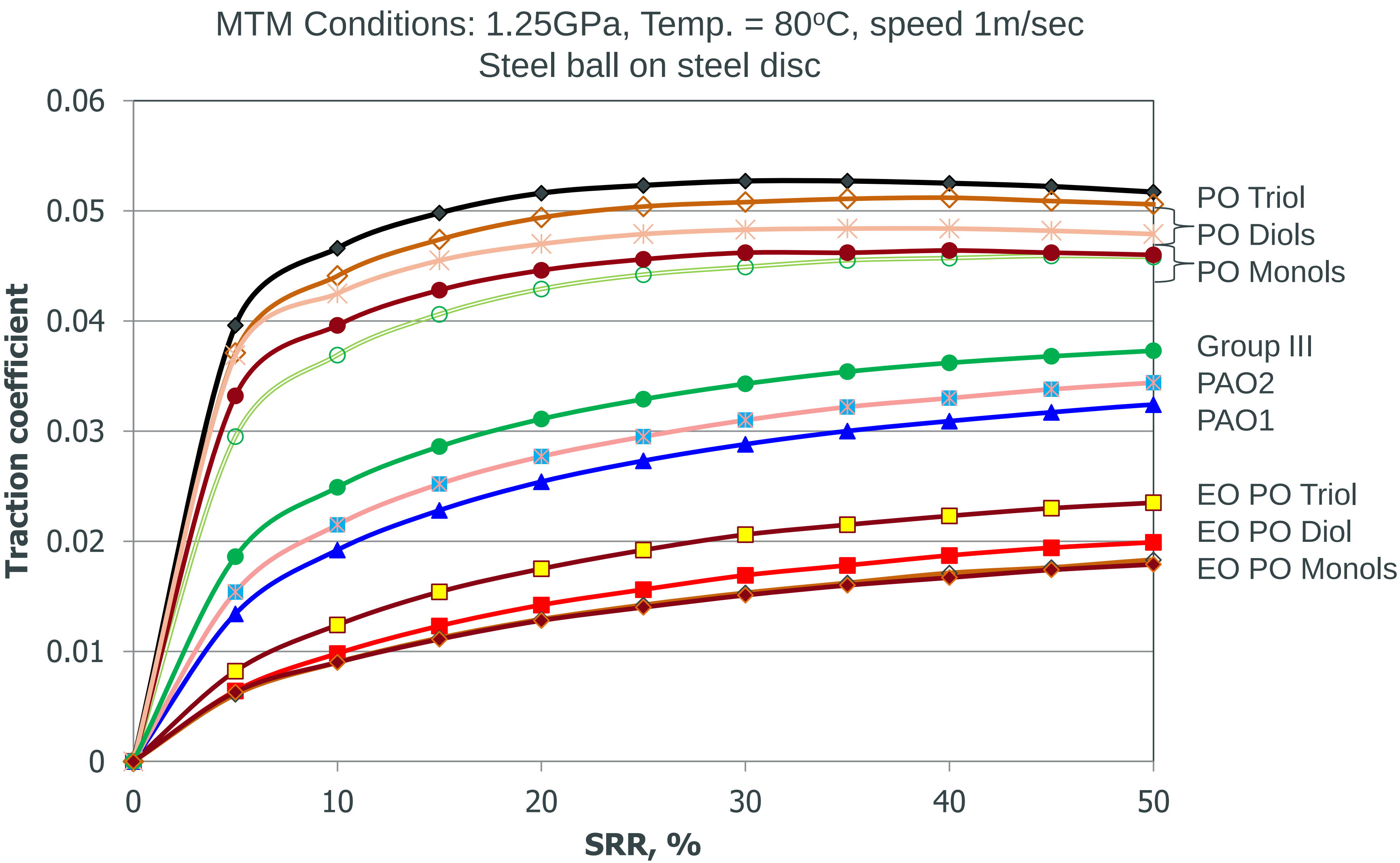
Branched (triol) structure exhibits higher traction values than "linear" (monol and diol) structures

Triol initiators – ISO150 PAGs

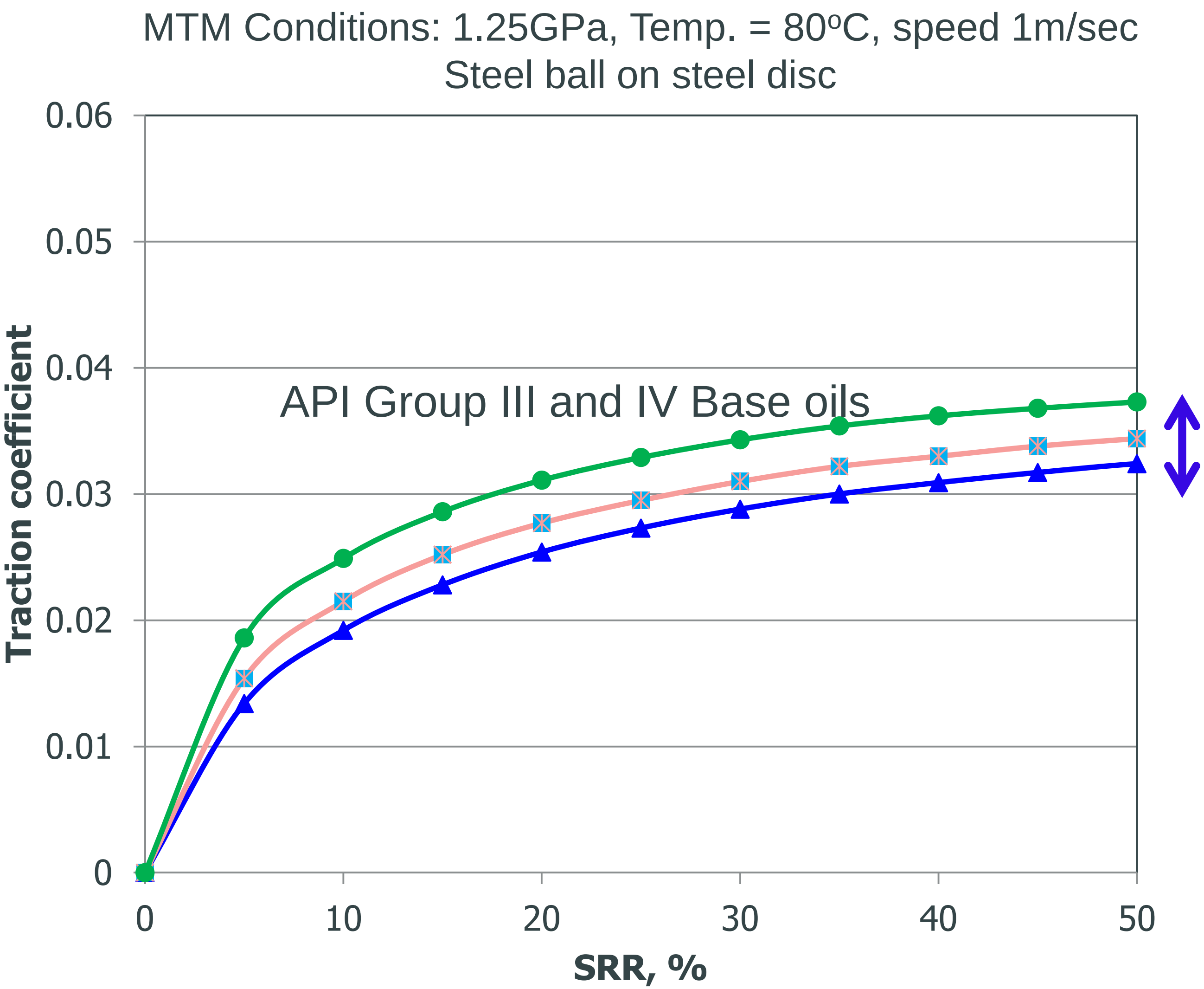


PO triol structures exhibit higher traction values than EO/PO Triol structures

PAGs and Hydrocarbon Oils (ISO46 to 150)

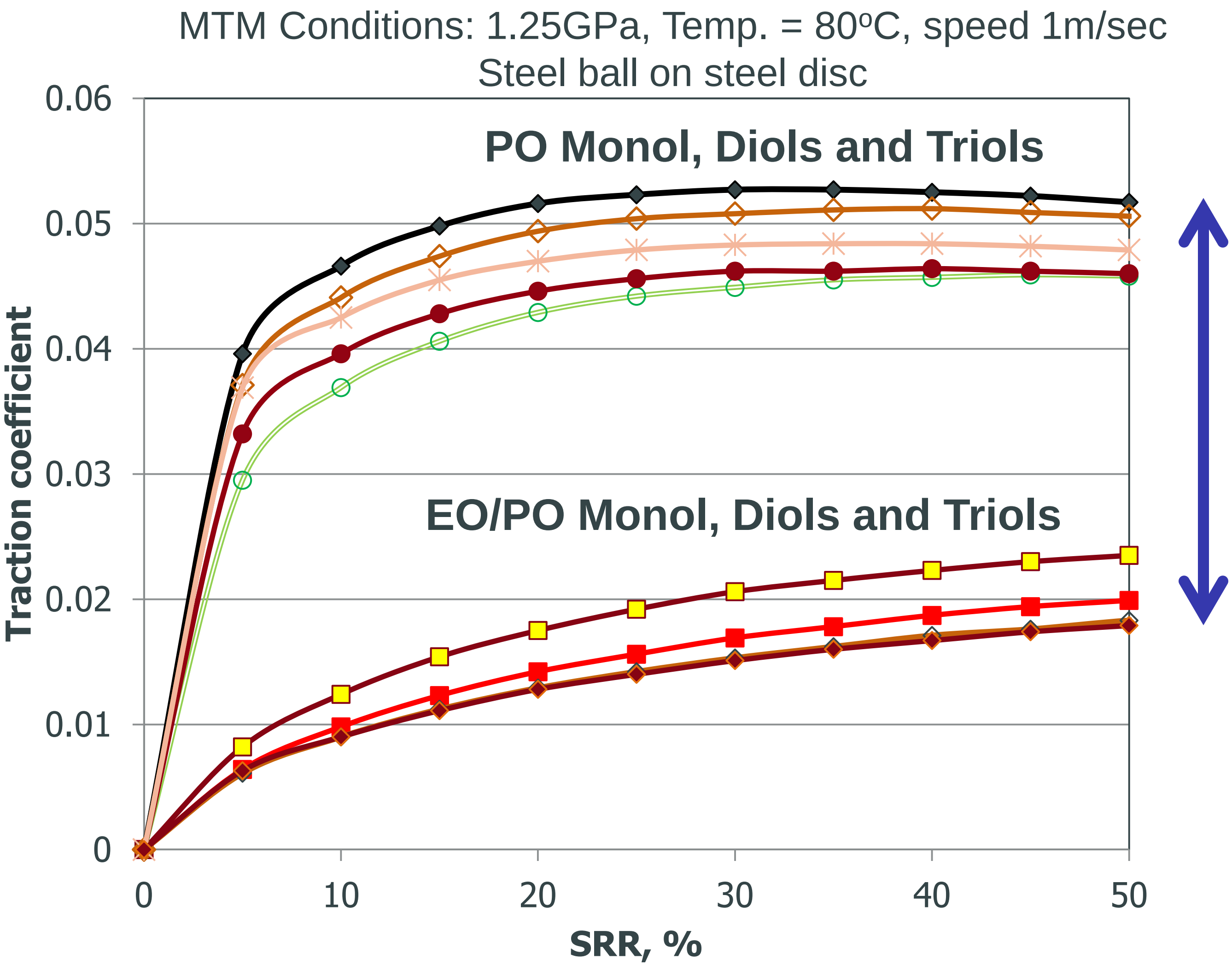


Hydrocarbon Oils



Narrow design space for hydrocarbon oils

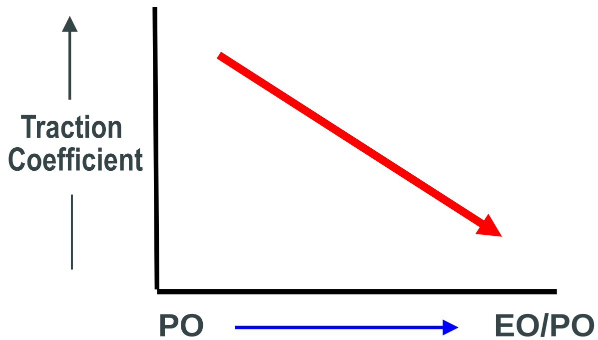
PAG Chemistries from ISO-46 to 150

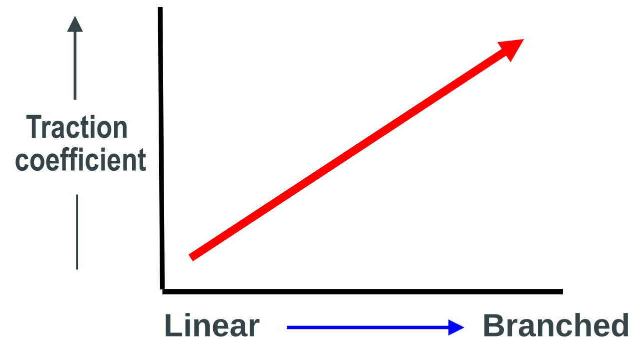


Wide PAG design space to control friction by varying the polymer architectures

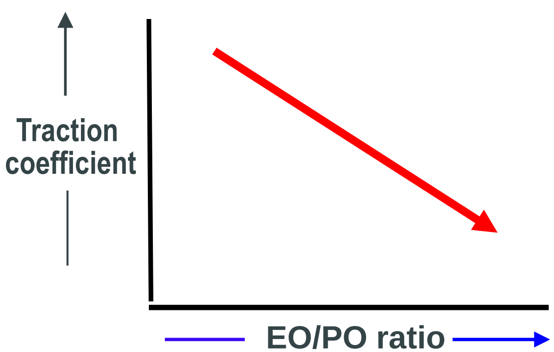
Design Rules

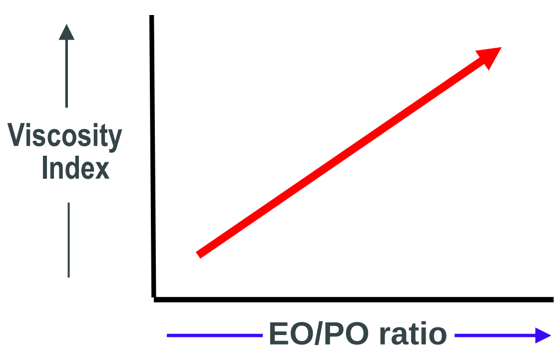
Generic Rules

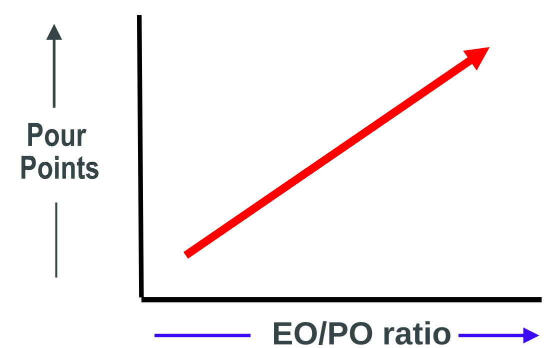




Design Rules for EO/PO Copolymers



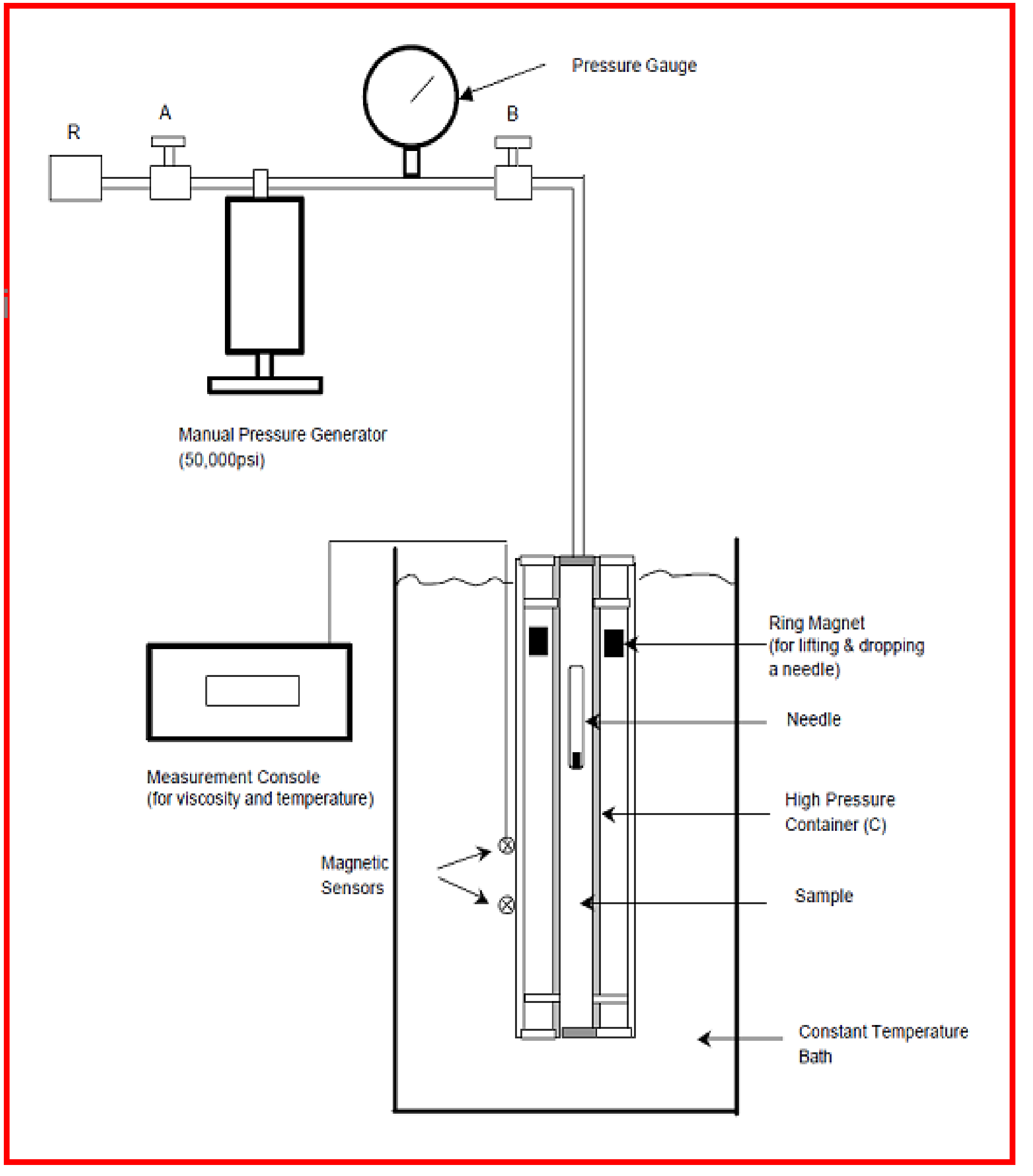




Measurement of Pressure Viscosity Coefficients

Apparatus

Falling needle high pressure viscometer
Measure viscosity at pressures to 50,000psi
Temperatures from 24 to 100^{o}C.

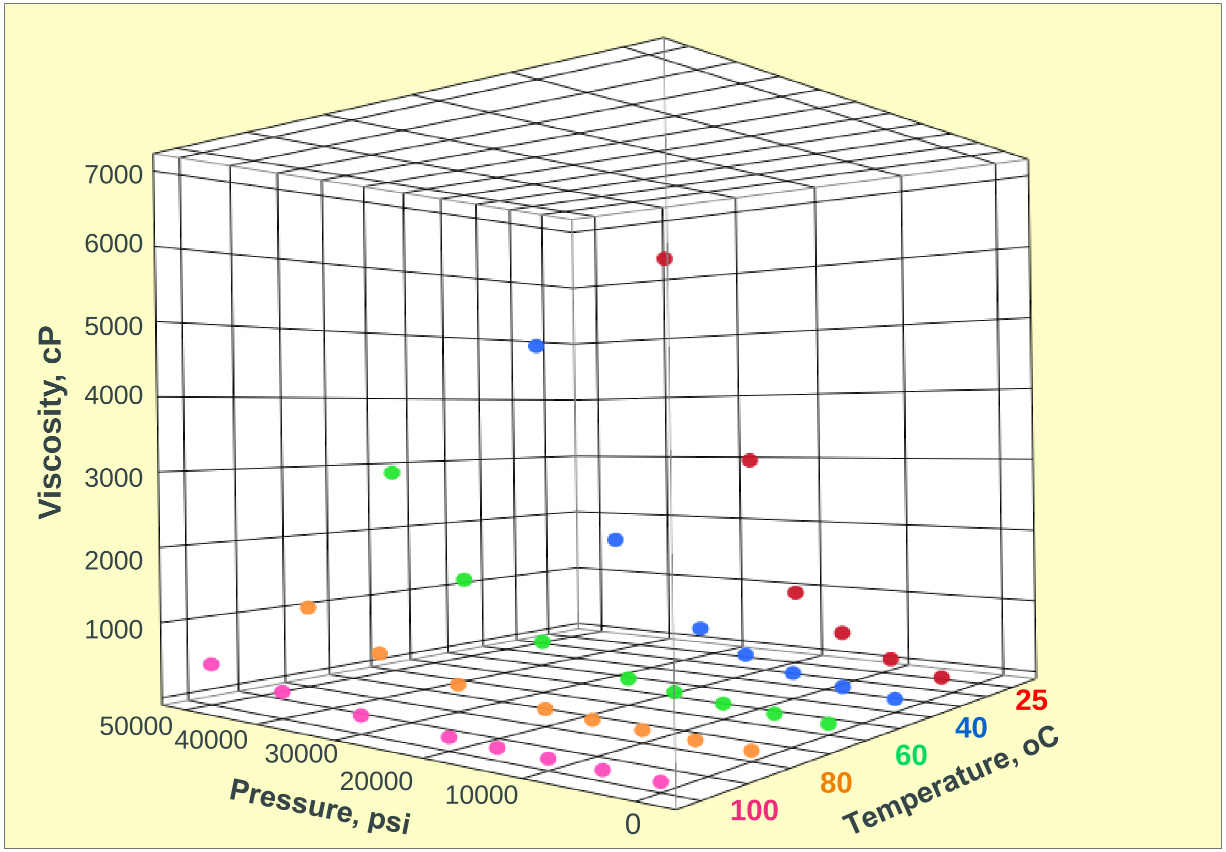


Model for Calculations

Roeland Equation

Example of Effect of Pressure on Viscosity

Increasing pressure can lead to a significant increase in a lubricant's viscosity



Example for an ISO-68 PAG Base Oil

An understanding of high pressure rheology is important for gears, roller element bearings and cams

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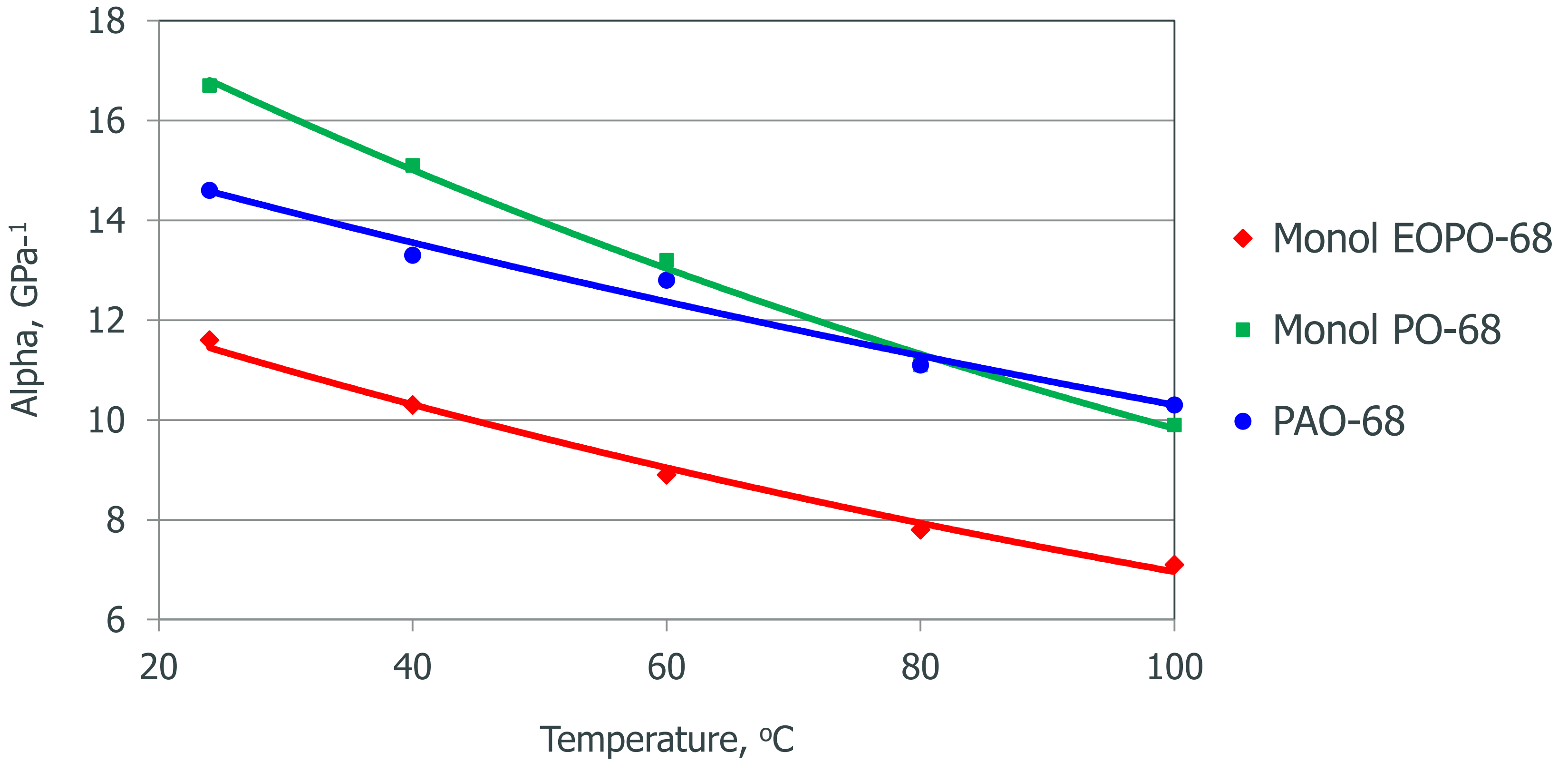
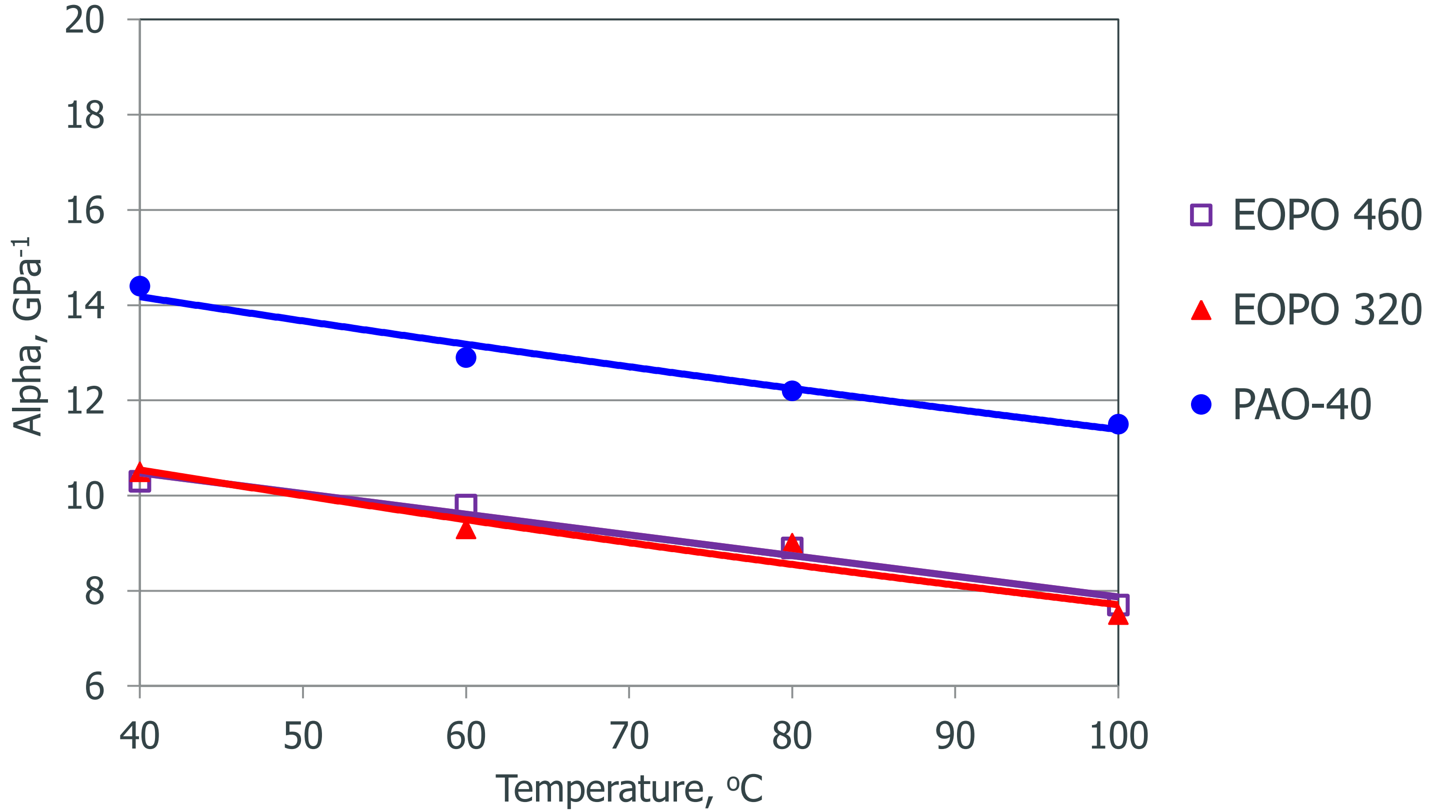
Alpha Values of PAGs based on Monols



Low viscosity EO/PO PAG (Monol) shows low alpha values across the temperature range

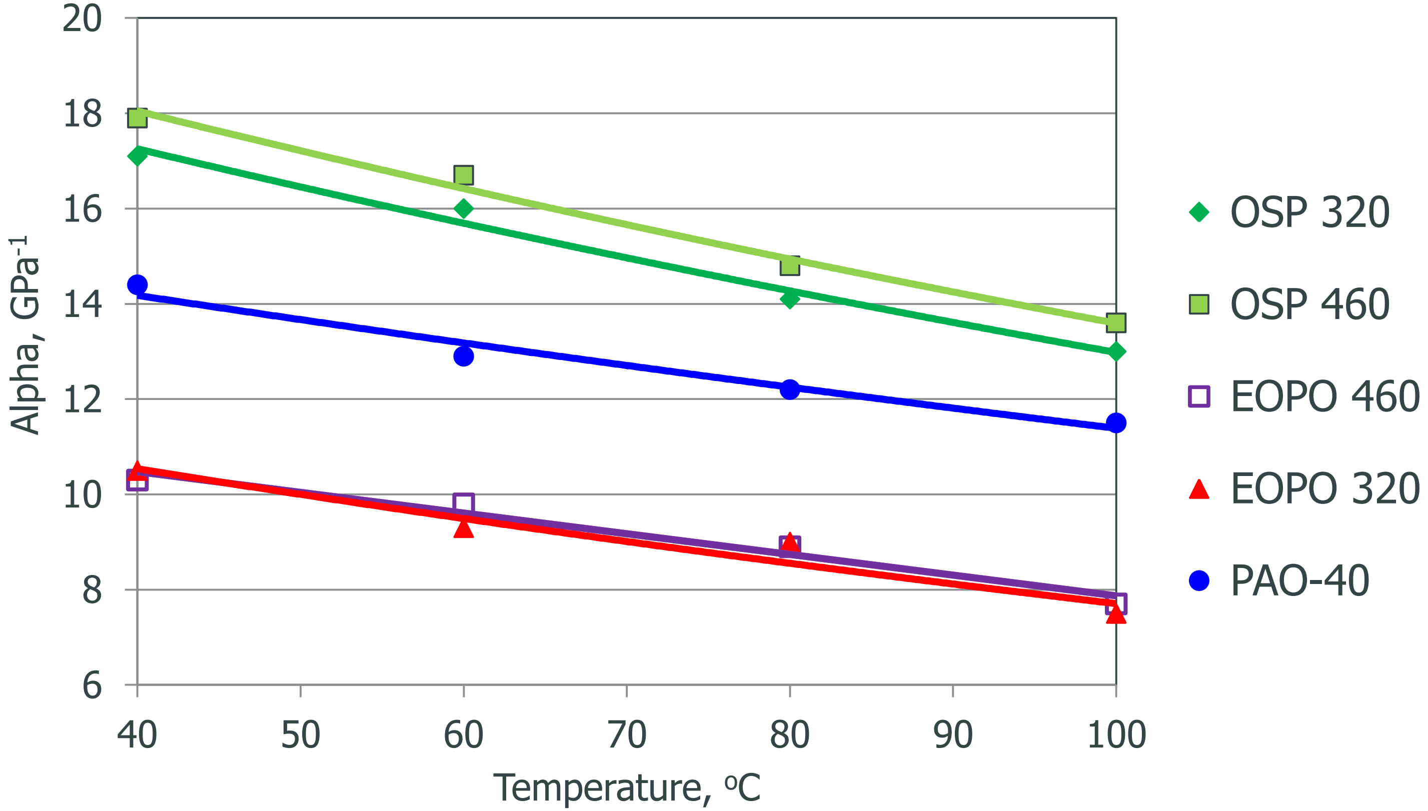
Alpha Values for PAG Diols (ISO-320 & 460)



High viscosity EO/PO PAGs (Diols) again show low alpha values across the temperature range.

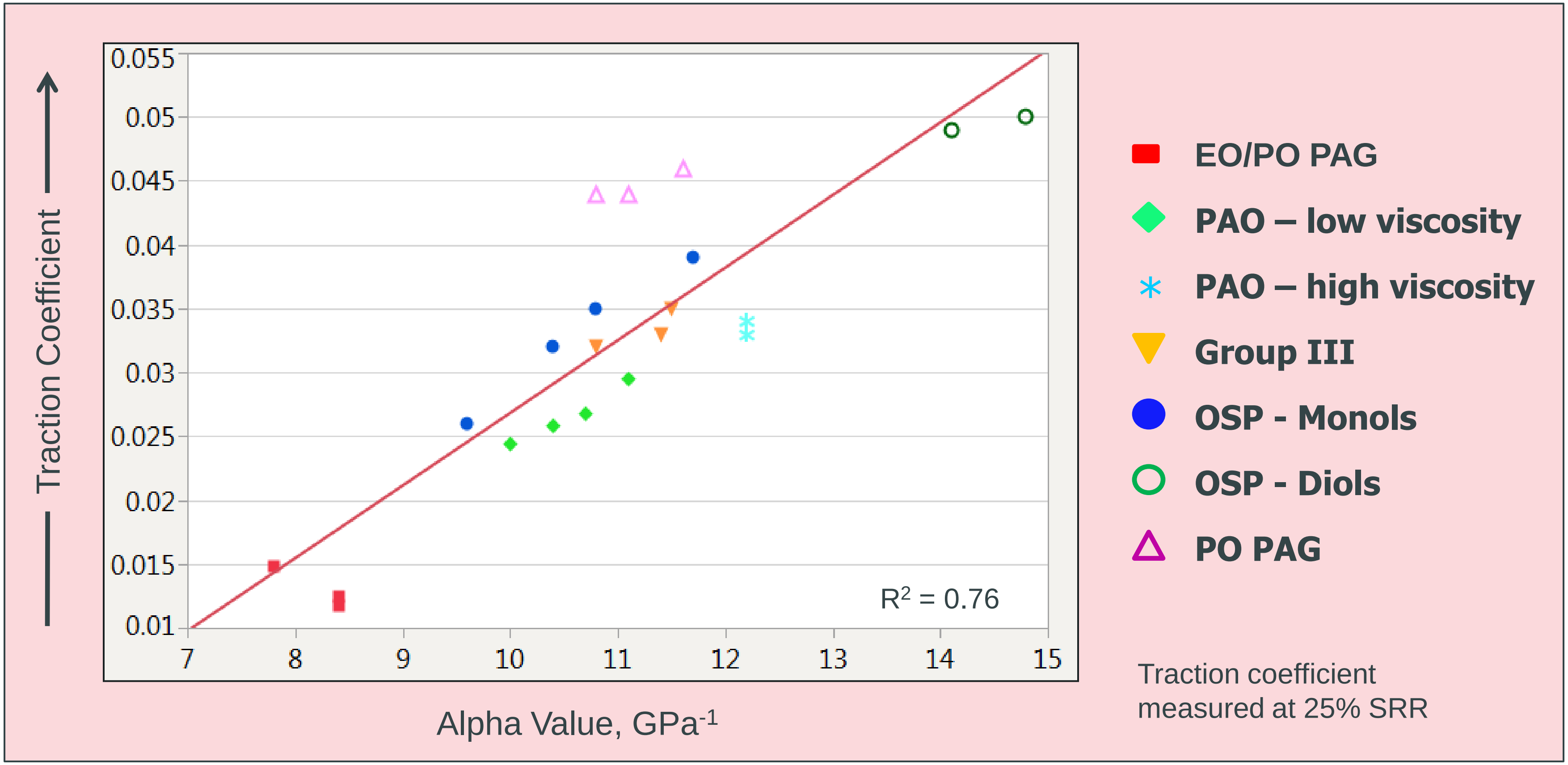
Alpha Values for OSPs (ISO-320 & 460)

Oil Soluble polyalkylene glycols (OSP) use butylene oxide as a building block



High viscosity OSPs show higher alpha values across the temperature range

Assessing the Correlation of Traction Coefficient & Alpha Values



Correlation between base oil traction value and alpha value at 80°C

But if designing energy efficient lubricants there is a potential practical dilemma.
Do you select a fluid with low traction value or one with a high alpha value?

EHD Film Thickness Measurements

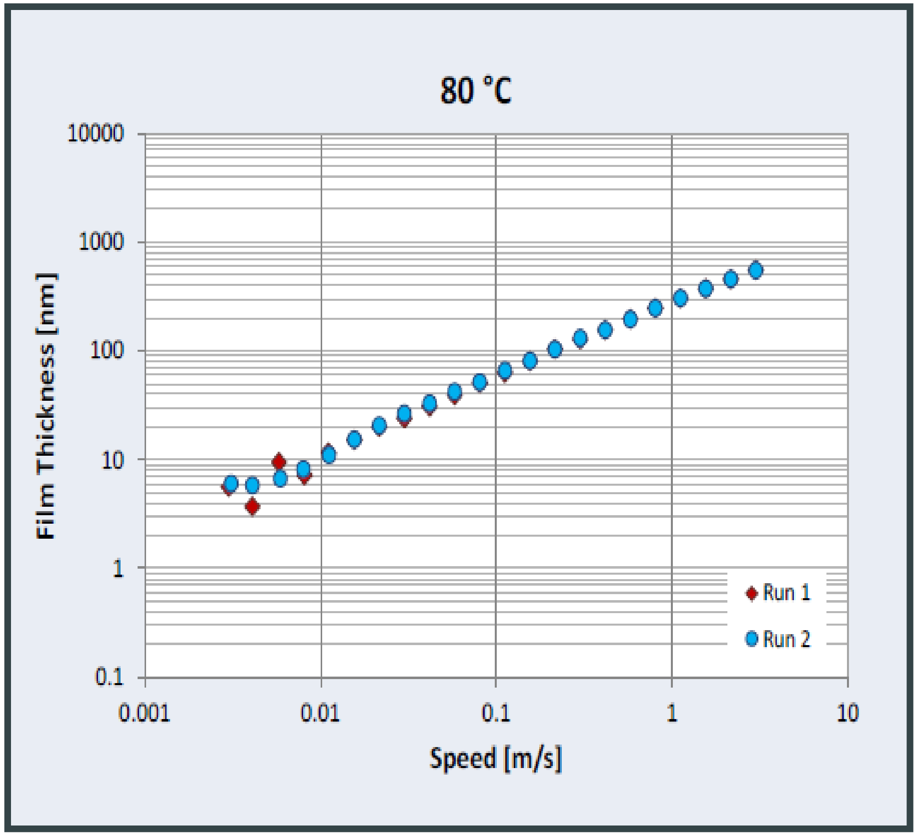
Assessed EHD Film Thickness for three formulated ISO-320 Gear Oils

- **a) EO/PO PAG**
- **b) Synthetic hydrocarbon (H-C) (PAO)**
- **c) OSP (Oil Soluble PAG)**

Method to Measure Film Thickness

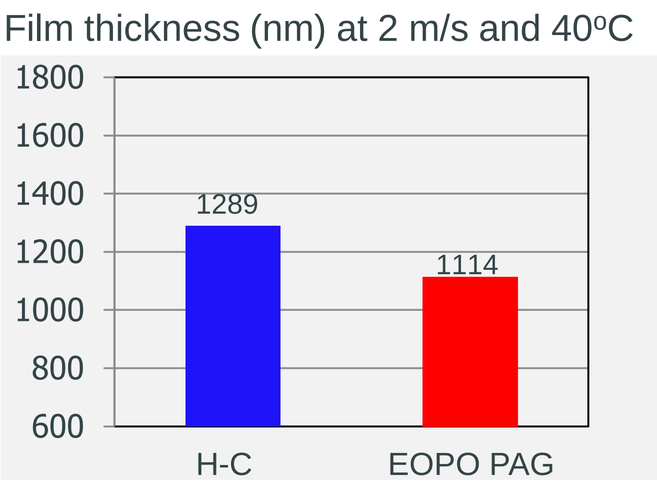
EHD Ultrathin Film Thickness Measuring Rig

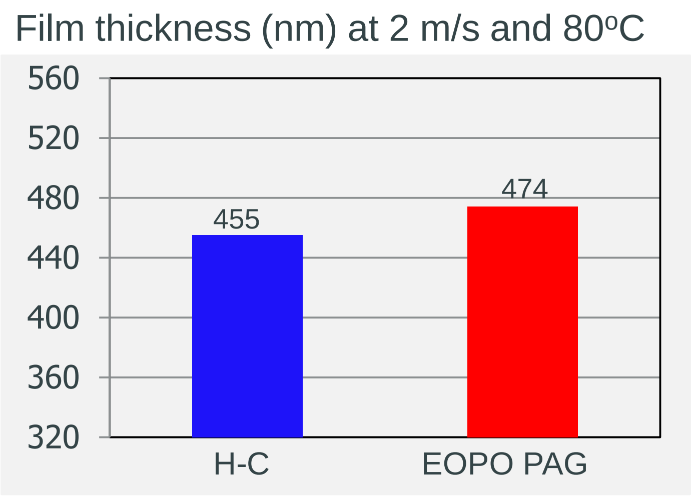
- Steel ball on a sapphire disc
- Pure rolling conditions (SRR = 0%)
- Temperature 40, 80, 120 and 150^{o}C
- Speed range is 0.003- 3 m/sec
- Load 41N (max. Hertz Pressure is 1.25GPa)

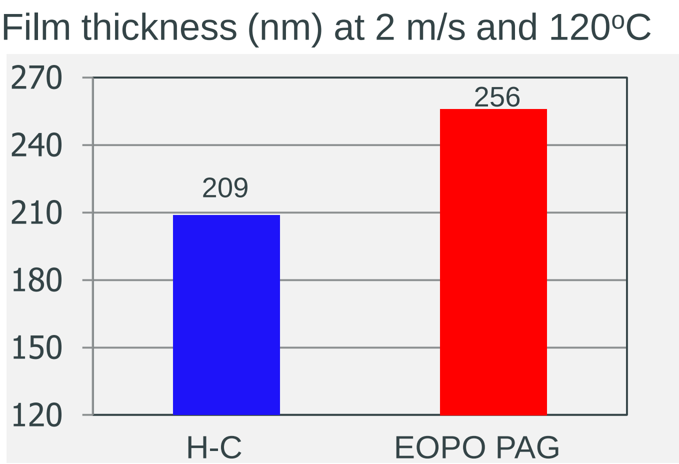


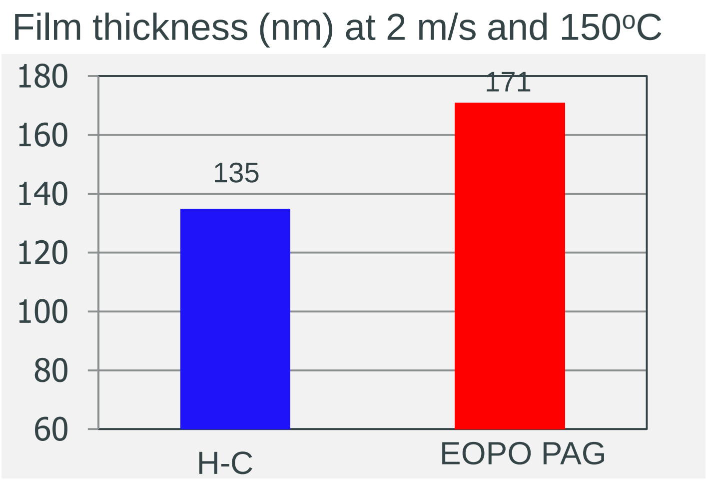
Typical PAG base oil profile
Film thickness measured at 2m/sec

EHL Film Thickness Measurements for ISO-320 Gear Oils









EO/PO PAG forms thick films at higher temperature

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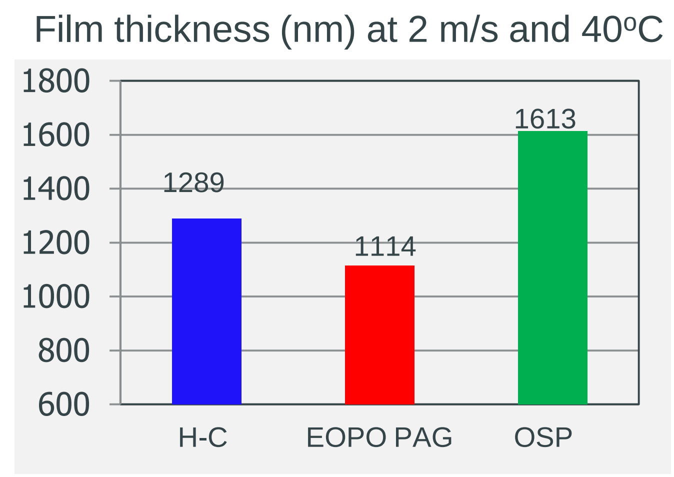
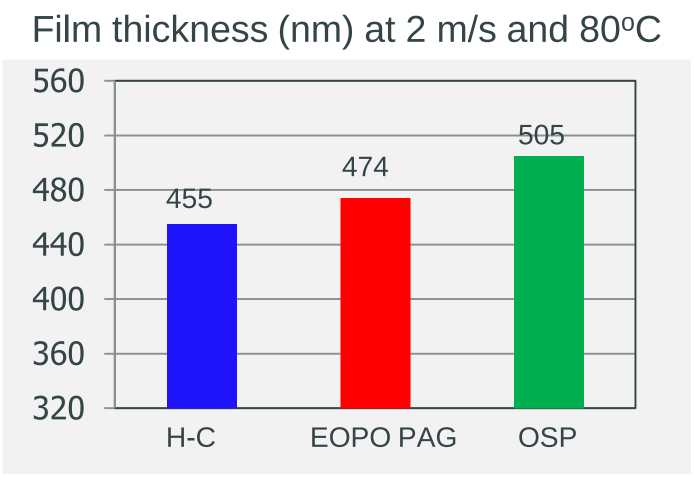
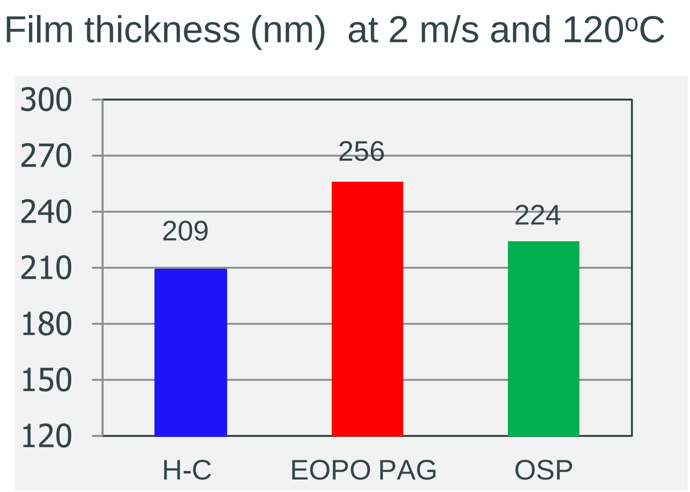
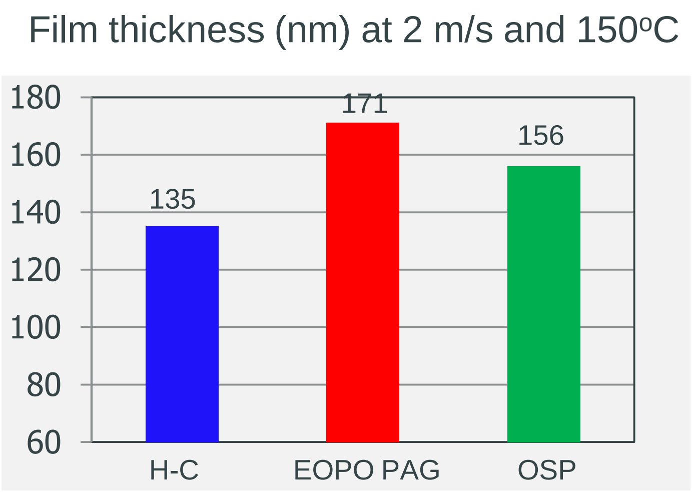
Data generated courtesy of Powertrib

EHL Film Thickness Measurements for ISO-320 Gear Oils









OSP forms very thick films across the temperature range

Conclusions

- Different polymer architectures can lead to broad differences in EHD traction values.
- Linear (Monol and Diol) EO/PO copolymers offer the lowest traction values.
- Branched (Triol) PAGs show higher traction values than linear structures.
- Lowest alpha values were observed for EO/PO copolymers
- Correlation exists between alpha and traction values.
- OSPs seem to offer the ability to offer very thick films – more research ongoing.
- Tailoring designing PAGs offers the potential to create “building blocks” for formulators looking to develop energy efficient solutions of the future.

Special Thanks

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Thank You

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