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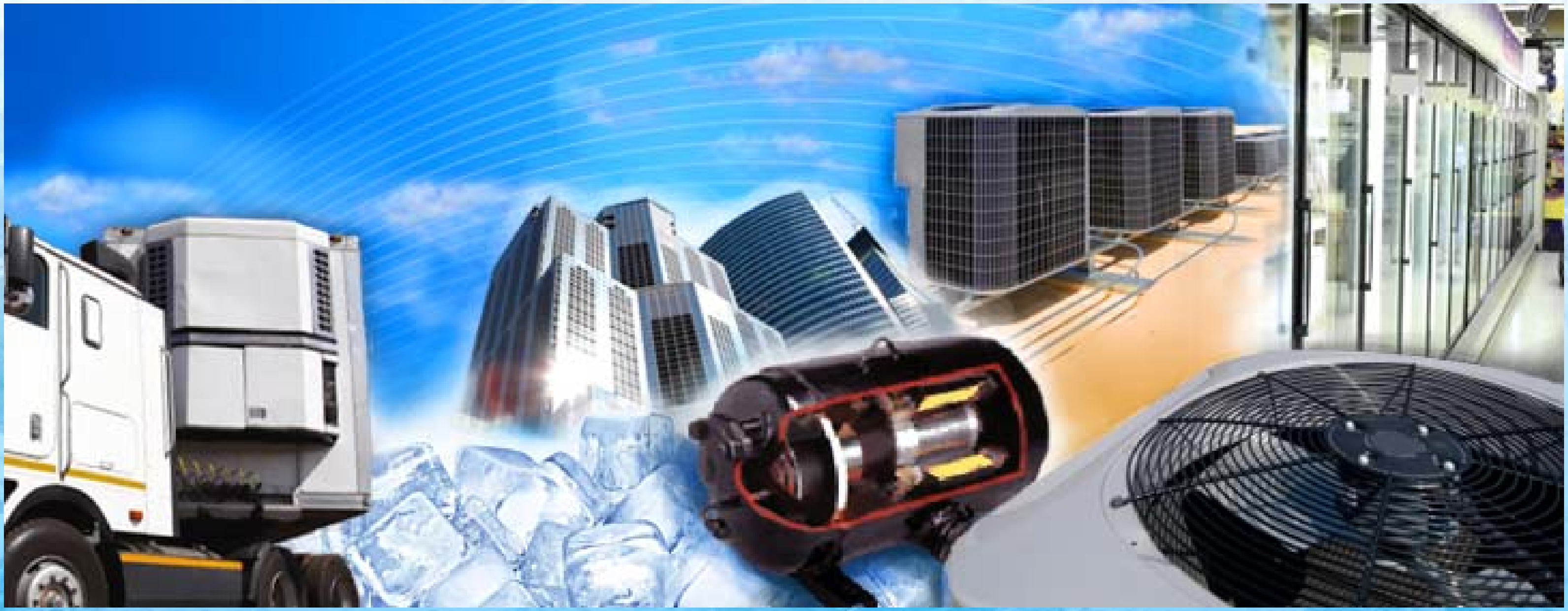
Fundamentals of Lubrication and the Development of Lubricants Optimized for Low GWP Refrigerant-based Applications



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Learning Objectives

- Distinguish between high and low GWP refrigerants.
- **Describe the important performance properties/criteria for a refrigeration lubricant.**
- Differentiate between different classes of synthetic refrigeration lubricants and their common areas of application.
- **Explain how differences in lubricant properties determines the correct lubricant choice for various low GWP refrigerants.**
- Describe what information is contained in a modified Daniel chart and how it can be used by a refrigeration compressor or refrigeration system designer.
- **Describe how the choice of lubricant for any particular refrigeration application impacts the overall performance of the lubricant/refrigerant mixture in both the compressor and heat transfer circuit.**

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Refrigeration Lubricants

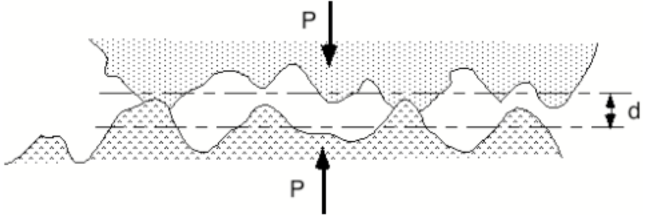
- The correct choice of refrigeration lubricant can:
  - Significantly reduce energy consumption in the compressor
  - Minimize losses in heat transfer efficiency in the refrigeration circuit

- A continued use of synthetics with current and future low global warming potential refrigerants

- Oxygenated synthetics are the most versatile
  - Polyalkylene Glycols
  - Polyol Esters
  - Polyvinyl Ethers

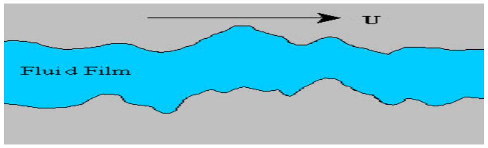
Lubrication Extremes

Boundary



- Direct surface-to-surface contact with high friction
- Lubrication dependent on lubricant lubricity (ability of lubricant to form protective molecular film).
- Lubrication is independent of viscosity
- Typically present at equipment start up and shut down (low speeds and high load)

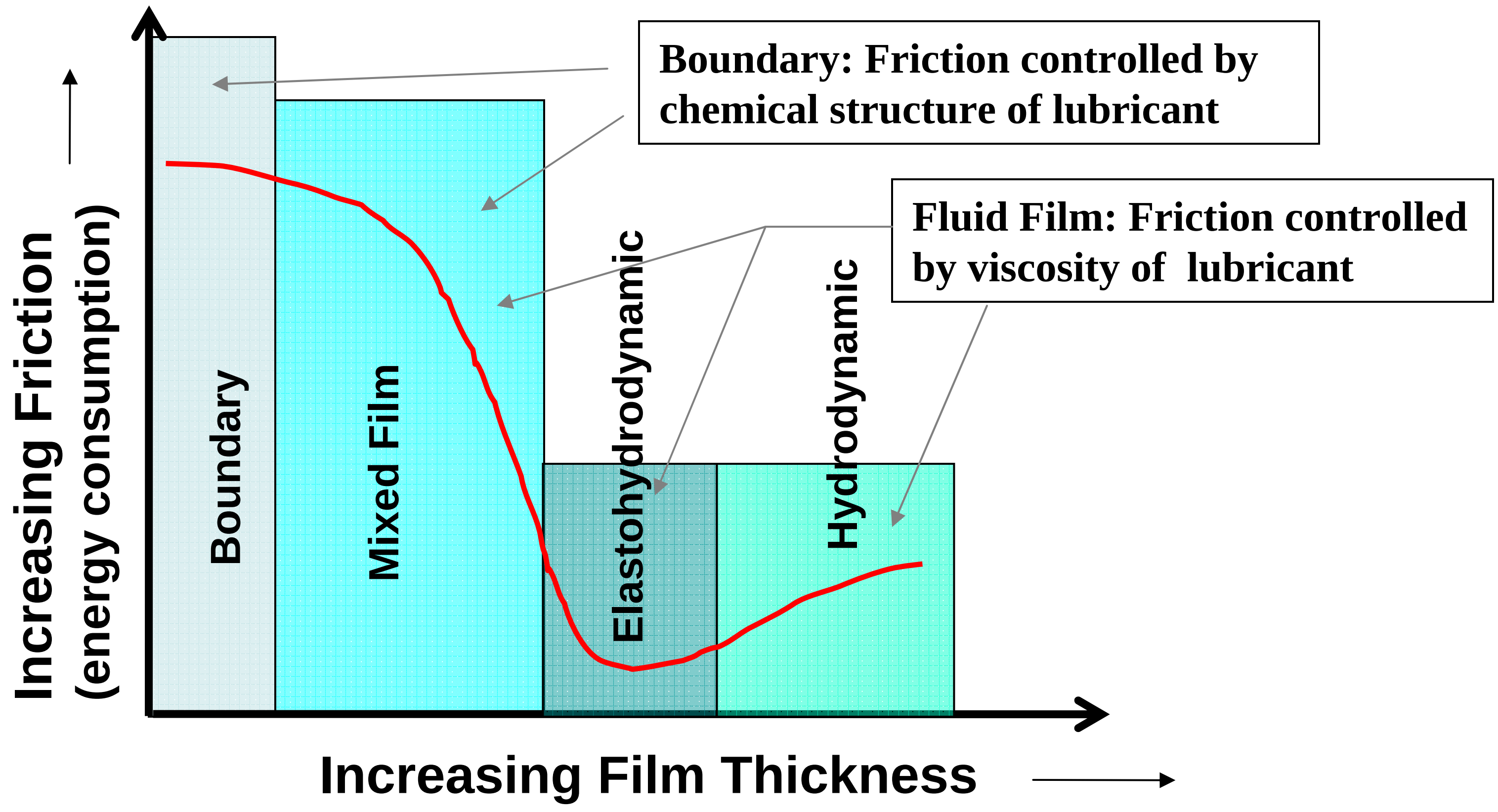
Fluid Film



- Lubricant film between surfaces with low friction.
- Lubricant entrainment produces a hydraulic effect that separates the surfaces.
- Film thickness dependent on the viscosity of the lubricant.
- Typically present during steady state high speed equipment operation

All designs of compressors experience both extremes in lubrication

The Stribeck Curve: Minimizing Friction and Energy Consumption



Boundary: Friction controlled by chemical structure of lubricant

Fluid Film: Friction controlled by viscosity of lubricant

- **Higher viscosity lubricant will achieve fluid film lubrication at higher loads and lower speed**
- **There is a film thickness that provides optimum energy efficiency.**

Performance Attributes of a Refrigeration Lubricant

- Reduce friction and prevent wear between moving parts in contact under load (bearings, valves, etc.)
- Seal clearances between low pressure (suction) and high pressure (discharge) sides to maintain compression ratio
- Dissipate heat from friction and gas compression
- Good low temperature flow
- High dielectric constant for hermetic applications

The lubricant must perform while mixed with refrigerant

- **In the compressor**
- **In the heat transfer circuit**

Compatibility of the Lubricant with the Refrigerant (Solubility and Miscibility)

	Compressor	**Refrigeration Circuit**
Consideration	**Solubility** of Refrigerant in Lubricant	**Miscibility** of Lubricant with Refrigerant
Concern/Issue	-Viscosity dilution of oil by refrigerant	-Avoid phase separation of lubricant and refrigerant in condensor/evaporator and lines
Result	-Too much: Loss of fluid film lubrication -Too little: Increased viscous drag	-Pooling of oil in heat exchangers -Oil films on heat exchanger surfaces -Insufficient oil return to compressor sump
Impact	-Increased compressor power consumption -Excessive wear/compressor failure	-Loss of heat transfer efficiency -Compressor failure

Lubricant design for optimum energy efficiency requires consideration of the compatibility of the refrigerant/lubricant combination in both the compressor and refrigeration circuit

Balancing Lubricant/Refrigerant Compatibility to Improve Overall Energy Efficiency

The more miscible one makes the lubricant with the refrigerant….the more soluble the refrigerant becomes in the lubricant

- Ensure sufficient miscibility of lubricant with the refrigerant to maximize heat exchanger efficiency in the refrigeration circuit and assure required oil return to compressor sump
- Optimizing the solubility of the refrigerant in the lubricant in the compressor to ensure fluid film lubrication while minimizing viscous drag.

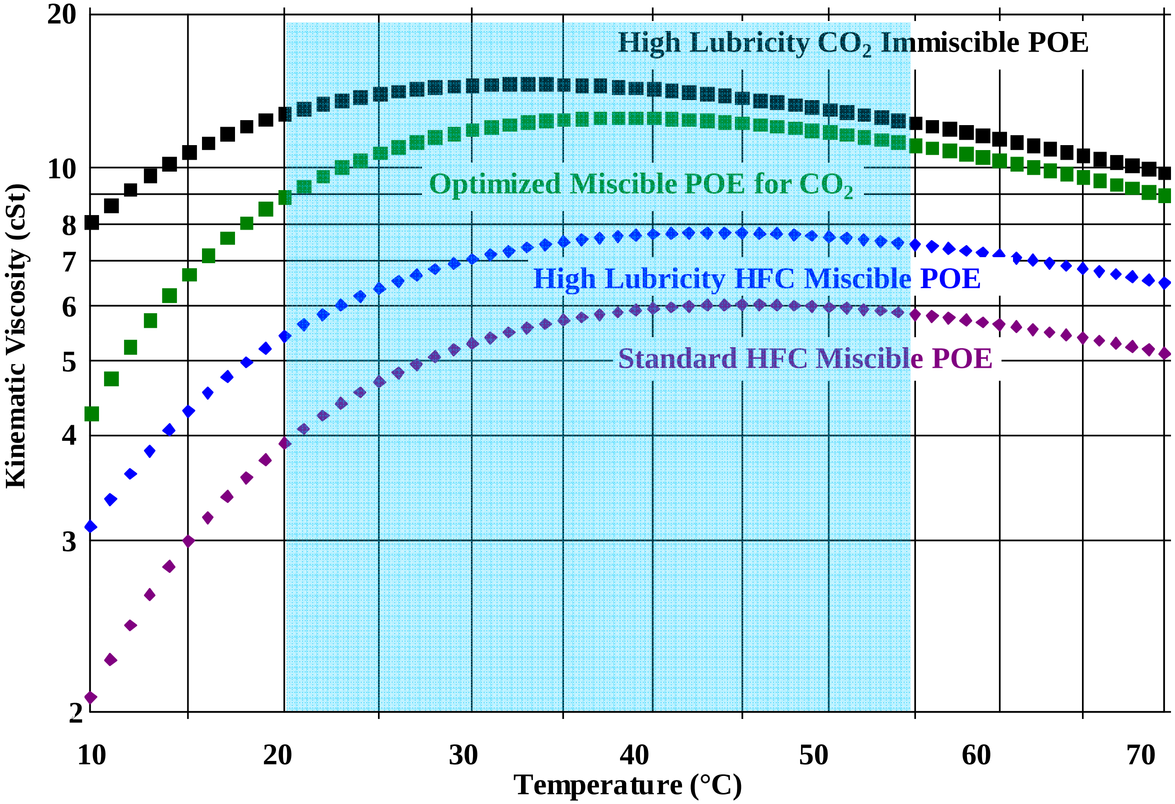
Example: Miscible Polyol Esters for Trans-critical Carbon Dioxide Applications

- Carbon Dioxide
  - ODP = 0, GWP = 1
  - Natural refrigerant
- Lubrication Challenges for Transcritical CO2 Refrigeration Systems
  - High operating pressures (> 120 Bar) place extreme loads and stress on bearings.
  - High solvency/solubility of CO_2 in commercial polyol esters leads to excessive viscosity reduction.
- The Impact
  - Insufficient fluid film lubrication, bearing wear and compressor failure
  - Improper sealing of clearances and loss of compression

Controlling CO_2 Solubility to Minimize Viscosity Dilution (ISO 68 Comparison)

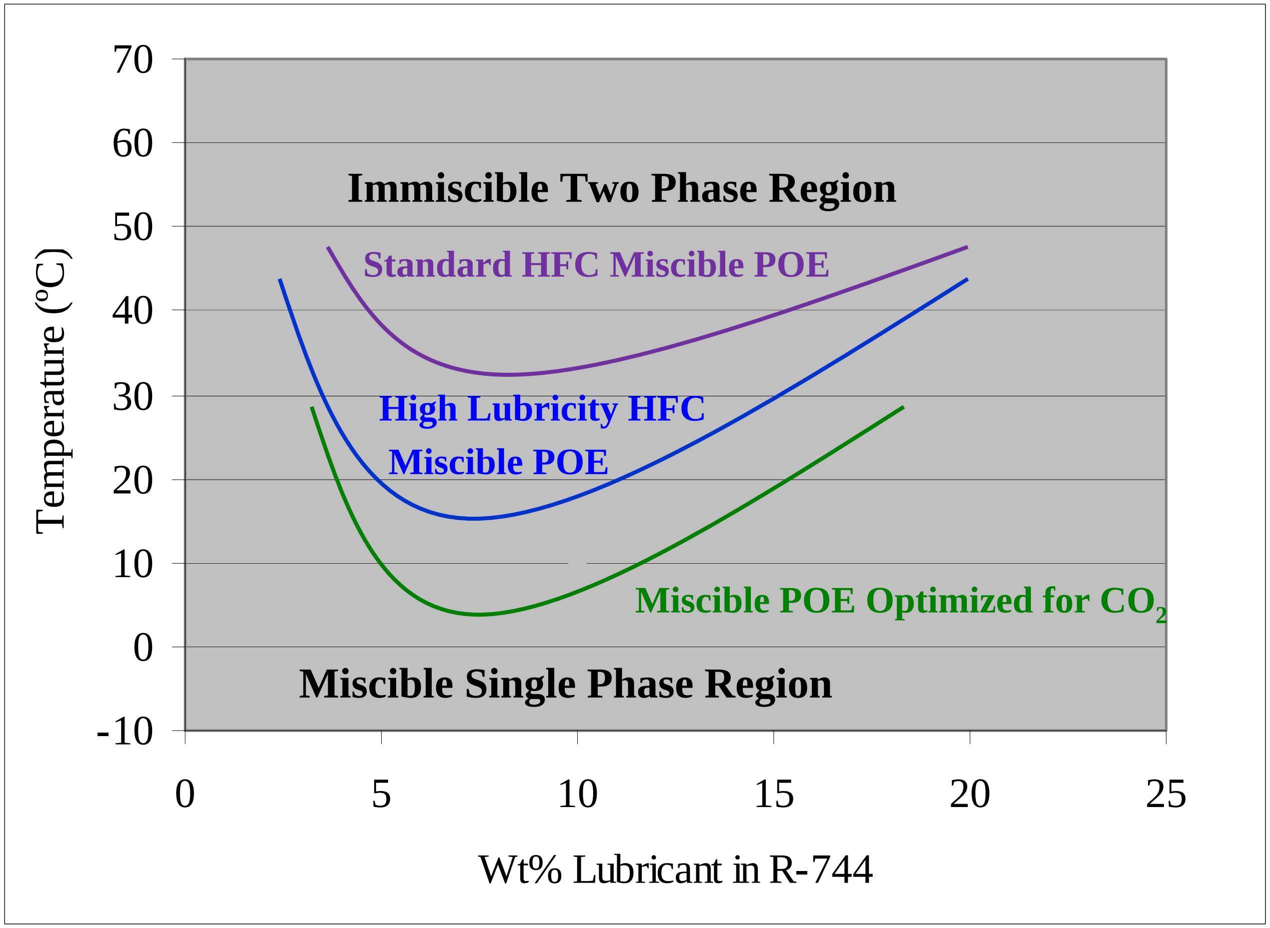
Viscosity as a Function of Temperature at 3.5 MPa

- **3.5 MPa represents a typical evaporator setting for a MBP transcritical system (0 ºC)**
- **Compressor sump temperature range = 20-55 ºC**



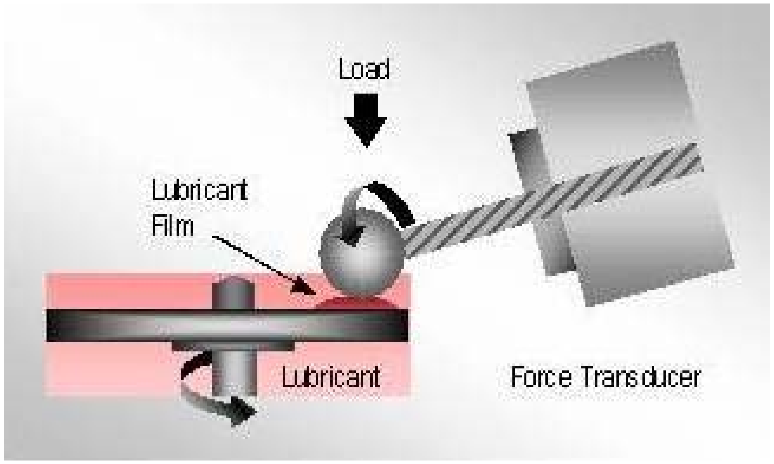
Modifications to polyol ester chemical structure and polarity can be used to control the solubility of the refrigerant in the lubricant.

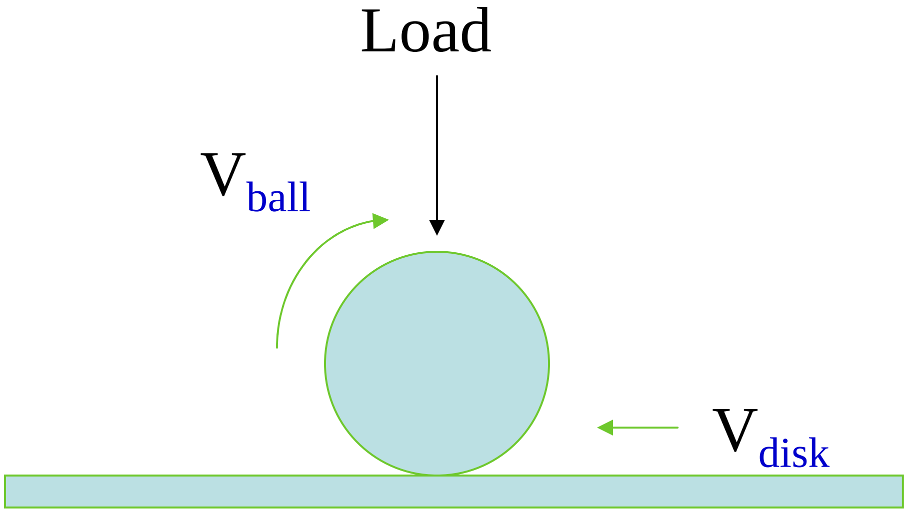
Miscibility Profiles for Several ISO 68 POEs in Carbon Dioxide (R-744)



Modifications to polyol ester chemical structure can be used to tailor miscibility properties.

Measuring the Lubricity Performance of Lubricants
Mini-Traction Machine





Contact Geometry

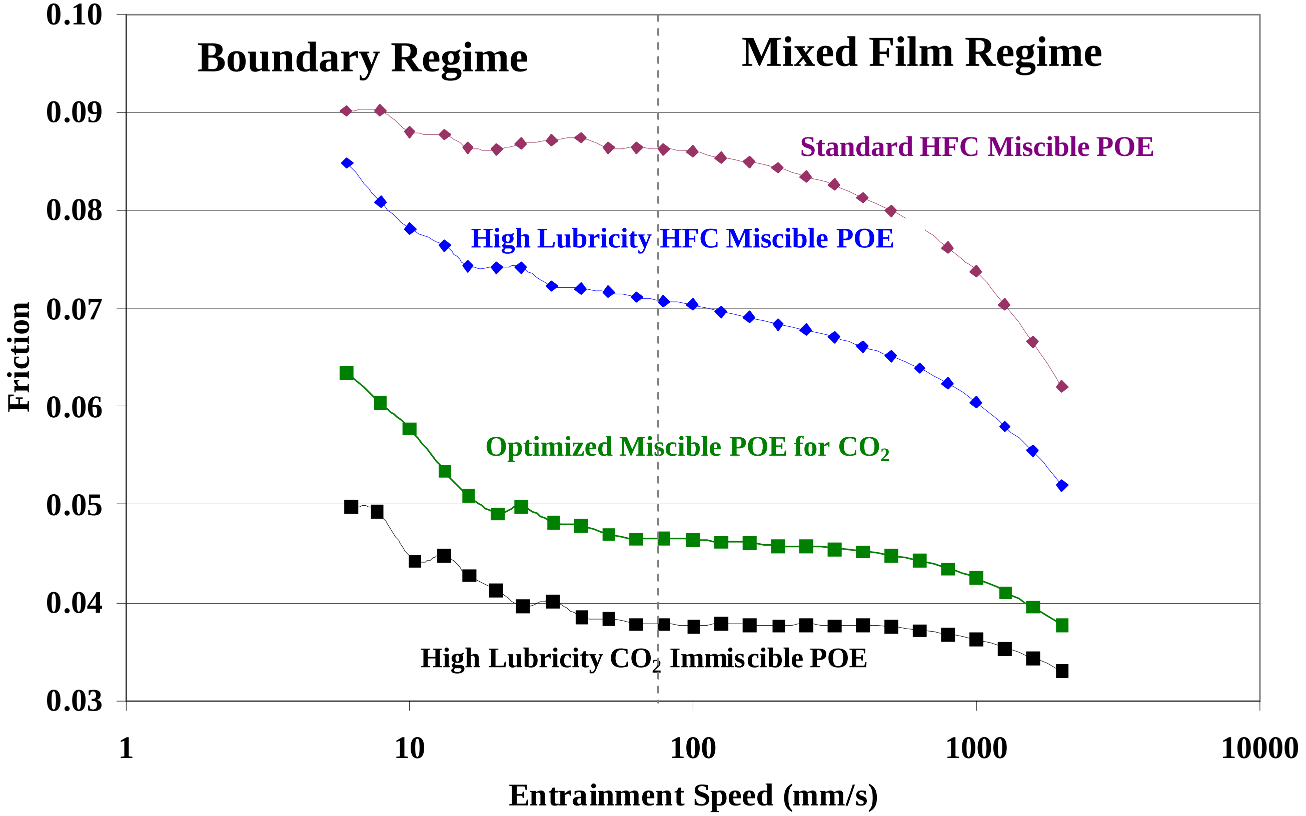
$$\text{Mean Entrainment Speed} = \frac{(V_{disk} + V_{ball})}{2}$$

$$\text{Slide Roll Ratio (SRR)} = \frac{2(V_{disk} - V_{ball})}{(V_{disk} + V_{ball})}$$

Reducing Frictional Energy Losses Under Boundary Lubrication Conditions

MTM Stribeck Curve at 40 °C for ISO 68 Lubricants

Coefficient of Friction as a Function of Entrainment Speed at 50 % SRR



Conclusions

- Lubricants must provide good lubrication under both boundary and fluid film conditions.

- An important lubricant property contributing to improved energy efficiency is optimized compatibility with the refrigerant (miscibility and solubility).

- The properties of synthetic lubricants can be optimized for a given refrigerant/application through modification of their chemical structure.

- Modification of polyol ester structure can be used to obtain a CO_2 miscible lubricant that has an optimized balance of refrigerant miscibility/solubility and lubricity performance.