Considerations for Changing Aluminum Cold Rolling Base Oil

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Reviewing the Function of the Base Oil*

- Enable the boundary additives to be supplied uniformly to the roll bite.
- Carry away loose debris from the rolling process to be controlled by filtration.
- Remove heat from the process, especially for mineral oil mills, enabling relatively constant tribological conditions and roll geometry.

* Focus is on aluminum. Presuming processes not needing base oil, such as minimum quantity application of boundary additives or the use of oil-free water-based solutions, remain future goals.

Some Reasons to Consider a Change

- **Commercial Availability Concerns**:
  - Incumbent unavailable and/or subject to force majeure
- Other factors:
  - TECHNICAL—Modified or more consistent base oil properties are desired, e.g., boiling point range, viscosity, composition. These can also impact rolled product customer satisfaction.
  - COMMERCIAL--Issues with cost, payment terms, on-time deliveries; customer desire to prequalify an alternate product. These are outside the scope of this discussion.
  - SUSTAINABILITY– Preferences of customer and/or rolling facility (likely to increase rapidly in importance).

Some Reasons to Resist a Change

Assuming the Incumbent Remains Available and its Issues aren't Overwhelming

- Purchased cost savings may only be modest. At a cost that is 5¢/L lower, 2,000,000L of usage are needed to save $100K.
- Environmental qualification may require costly stack emissions studies.
- Customer qualification can require extensive trials with careful segregation of the trial oil.
- The pain of an unsuccessful conversion will be long remembered by plant personnel!

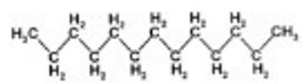
Cold Rolling Base Oil Options

Limiting the Discussion to Hydrocarbons

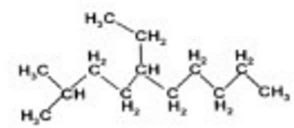
- Petroleum--Kerosene Sourced
  - Narrow cuts, usually hydrotreated
  - Isolated from kerosene, e.g., linear paraffins
- Synthetic
  - Olefin oligomers, e.g., derived from butenes
  - Branched and linear paraffins from the Fischer-Tropsch process
    - Very limited availability at present
    - Can be sustainable depending on carbon source

Hydrocarbon Molecular Structures

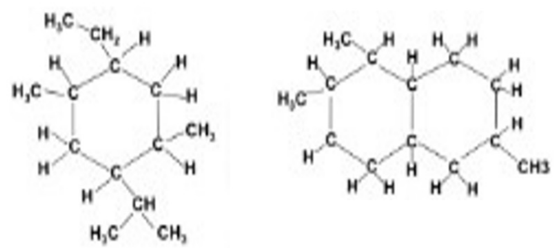
Normal Paraffin



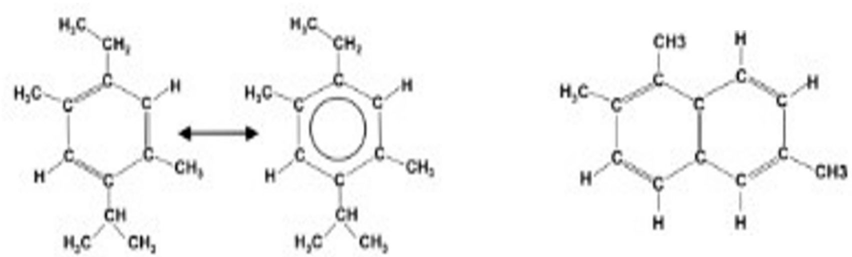
Isoparaffin



Cycloparaffin (Naphthene)



Aromatics



Sustainable Base Oil Options*

- Current/Future generation of hydrocarbons from sustainable sources, followed by fractionation to the desired boiling point range. Much of this is driven by vehicle and aircraft fuel applications. [** denotes approval of the route for blending into commercial aircraft fuel]
  - **Fischer-Tropsch generation of hydrocarbons from syngas produced from CO_2 or other sustainable feeds
  - **Chemical conversion of biobased fats and oils
  - **Chemical conversion of alcohols from sustainable sources
  - Yeast-Based process to farnesane (C_{15} isoparaffin)

*See Chemical & Engineering News, June 13, 2022

Technical Considerations (1)

- Composition
  - In the U.S., FDA regulatory compliance for indirect food additives, e.g., mineral oil used for rolling, includes meeting 21 CFR §178.3620(c)—a key is meeting UV absorbance limits associated with polycyclic aromatic hydrocarbons.
  - Linear paraffins and severely hydrotreated kerosene fractions with ≤1% aromatics are leading options and typically meet the more demanding 21 CFR §178.3620(b):
    - have low odor, desirable in the mill environment
    - have successfully met customer requirements, including taste for beer/beverage products

Technical Considerations (2A)

- Boiling Point Range (1)
  - The initial boiling point (IBP) and lower portion of the boiling point range influence vapor generation in and around the mill.
    - Lower IBP can increase the likelihood of ignition (severe fire risk!).
    - Depending on mill emissions controls, a lower IBP may increase VOC emissions and exceed regulatory limits.
      - If in doubt, expensive and experimentally difficult VOC compliance testing may be required.

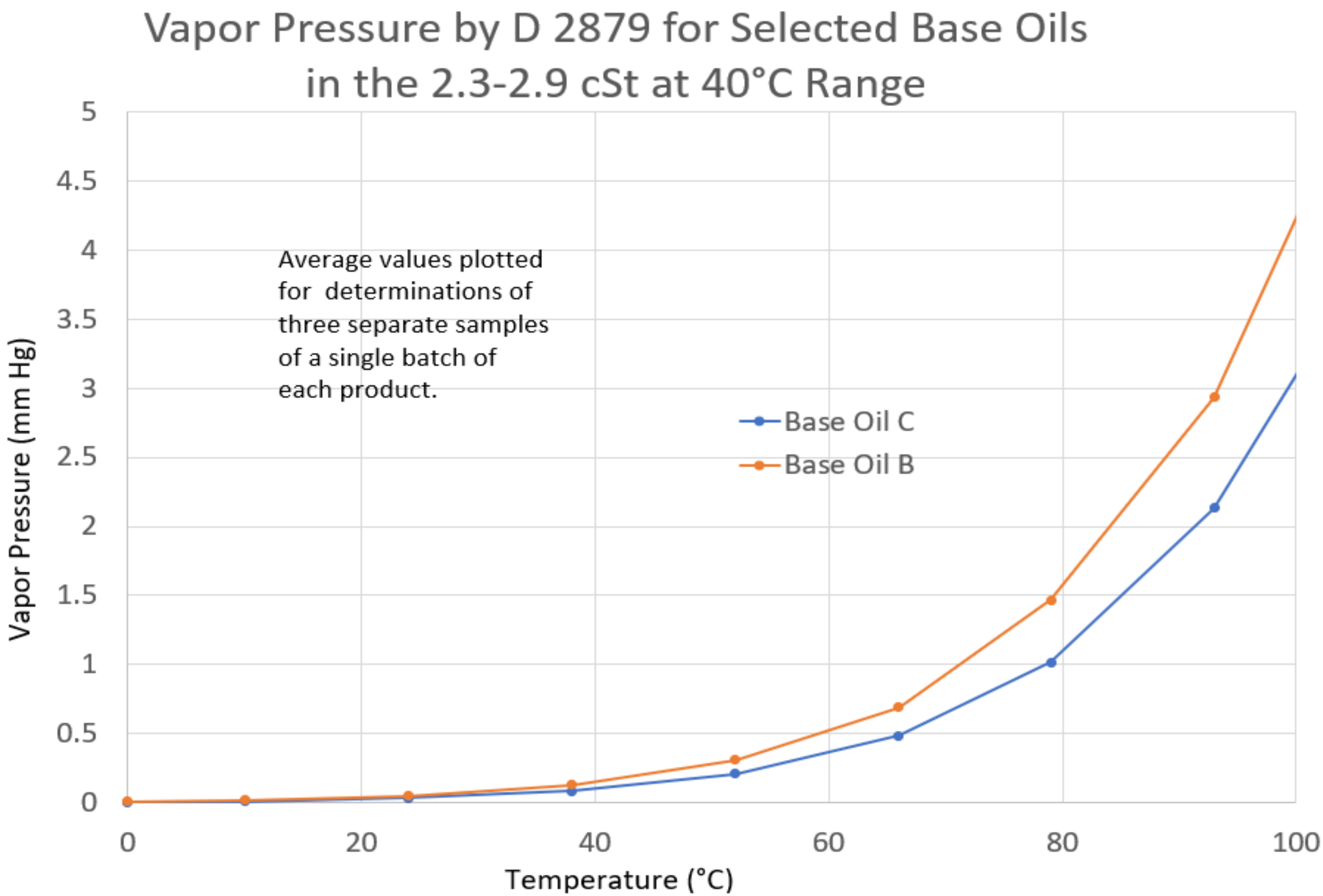
Technical Considerations (2B)

- Boiling Point Range (2)
  - Oils with higher final boiling point (FBP) and/or end point (EP) usually have higher viscosity and can have greater film thickness (and potential for slip) in the rolling contact unless rolling conditions are adjusted. [Machinery lubricant contaminants and any heavy boundary additives can also contribute.]
    - Higher boiling / more persistent residues on the sheet can:
      - Lead to undesirable staining.
        - » Stain testing can be done on exposed bare aluminum or, better, in stacks of sheets under simulated anneal conditions
      - Impact customer downstream processes.
      - Potentially exceed FDA limits for lubricant residues (23.2 mg/m^2).

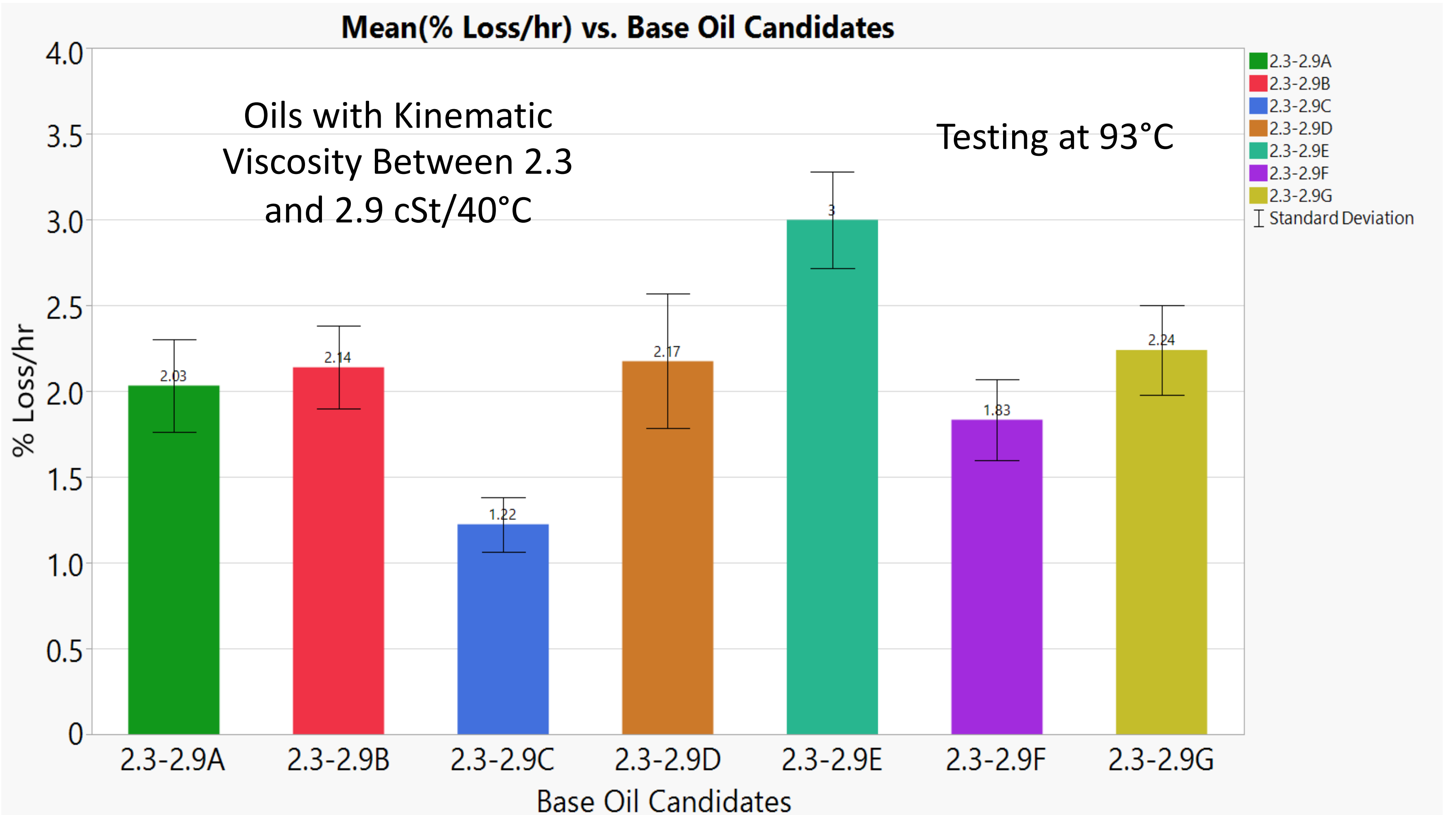
Technical Considerations (2C)

- Boiling Point Range (3)
  - Bottom line—narrower range is preferred

Emissions Tendency by Isoteniscope



Notable Differences in Volatility of Cold Rolling Base Oils Seen in Evaporation Test in Oven



ALLEGHENY PETROLEUM

Technical Considerations (3)

Property	Hydrotreated Kerosene	Linear Paraffin	Comment
Viscosity and Temperature-Viscosity		+?	Lower viscosity enables higher rolling speed without slip
Viscosity-Pressure		+	Less viscosity increase at contact pressures
Density		+	Up to ~5% more volume for a given weight
Pour Point	+		Linear paraffins need warming at low ambient temperatures
Heat Transfer		+	Improved roll temperature consistency
Autoignition Temperature	+		Potentially less prone to ignite
Additive Effectiveness		+?	Probable reduced solvency—more additive affinity for surface

Viscosity Considerations

Base Oil Viscosity in the Rolling Contact is Influenced by the Temperature and the Pressure Viscosity Coefficient (α). Compared to (linear) paraffins, base oils with significant naphthene content can be expected to thin out more as temperature increases and to thicken more as pressure increases.

Wilson-Walowit Equation

$$h_i = \left[\left(\frac{3\, n\, a\, (U + V)}{1 - e^{-a(Y - S)}} \right) \times \left(\frac{R}{g_1 - g_2} \right) \right]^{1/2}$$

Variable	Change	Effect on h_i
Reduction $g_1 - g_2$	↑	↓
Alloy, temper Y	↑	↓
Back Tension S	↑	↑
Rolling Speed U, V	↑	↑
Oil Viscosity n	↓	↓

- h_i = inlet film thickness
- n = fluid viscosity at inlet temperature
- a = pressure viscosity coefficient of fluid
- U = inlet sheet velocity
- V = roll velocity
- Y = inlet sheet yield stress
- S = unwind tension
- g_1 = inlet sheet thickness
- g_2 = outlet sheet thickness
- R = roll radius

Viscosity-Pressure Coefficient (α)

- Increasing pressure “packs” the base oil molecules.

$$\eta = \eta_0 \, e^{\alpha p}$$

- The viscosity in the roll bite tends to increase more for more complex hydrocarbons, leading to greater film thickness.

Summary

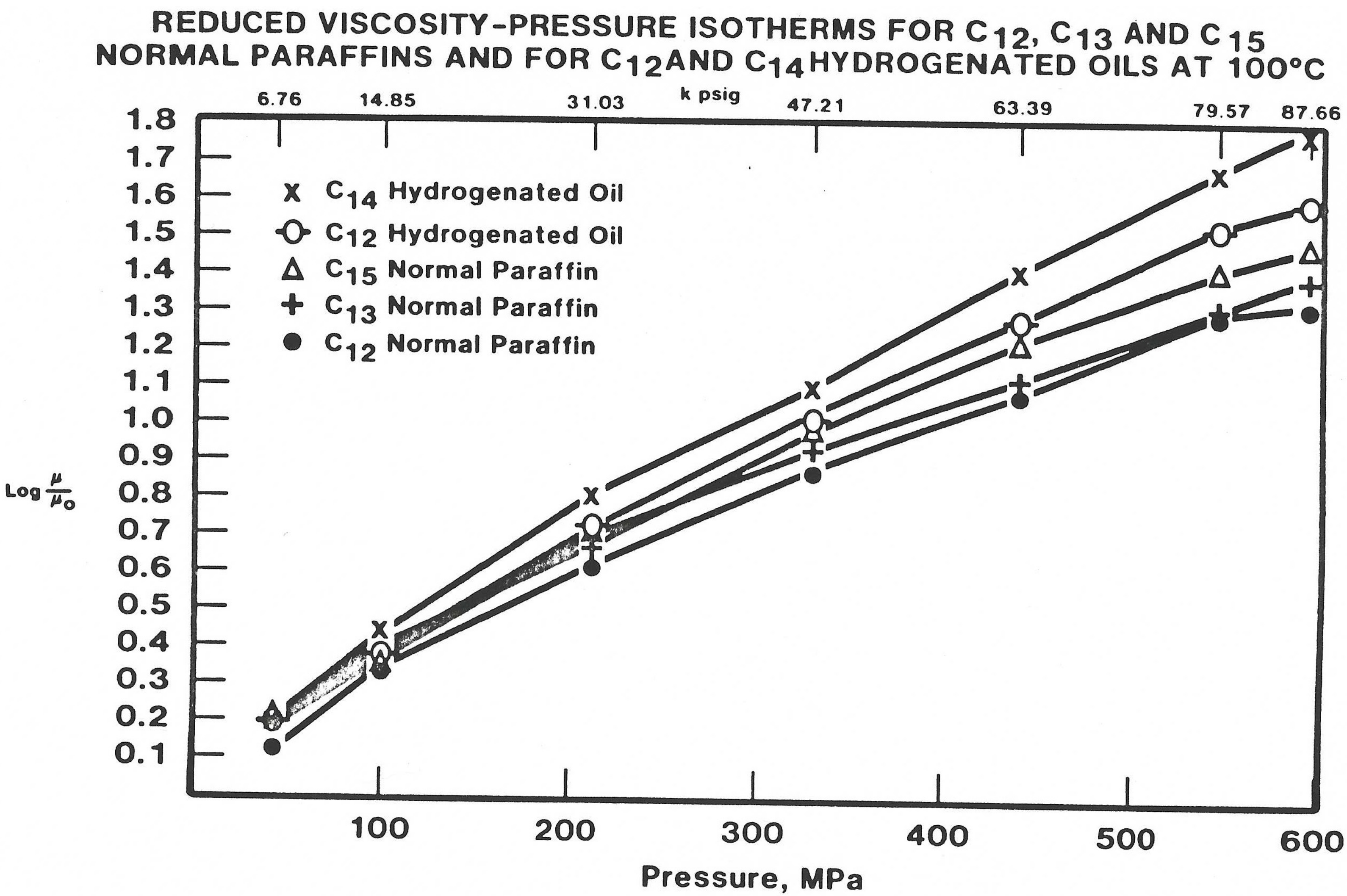
- Many factors enter into a decision to change cold rolling base oil—it's complicated!
- While technical concerns are important along with commercial concerns, sustainability concerns need to be considered for the future.

Acknowledgments

- Thanks to:
  - Allegheny Petroleum Products for support in preparing and presenting this paper.
  - You for your attention!

Addendum

Impact of Pressure on Viscosity for Linear Paraffin vs. Hydrotreated Kerosene



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