Estimation of Refrigerant-Oil Mixture Viscosities for Alternative Refrigerants Using Solubility Data

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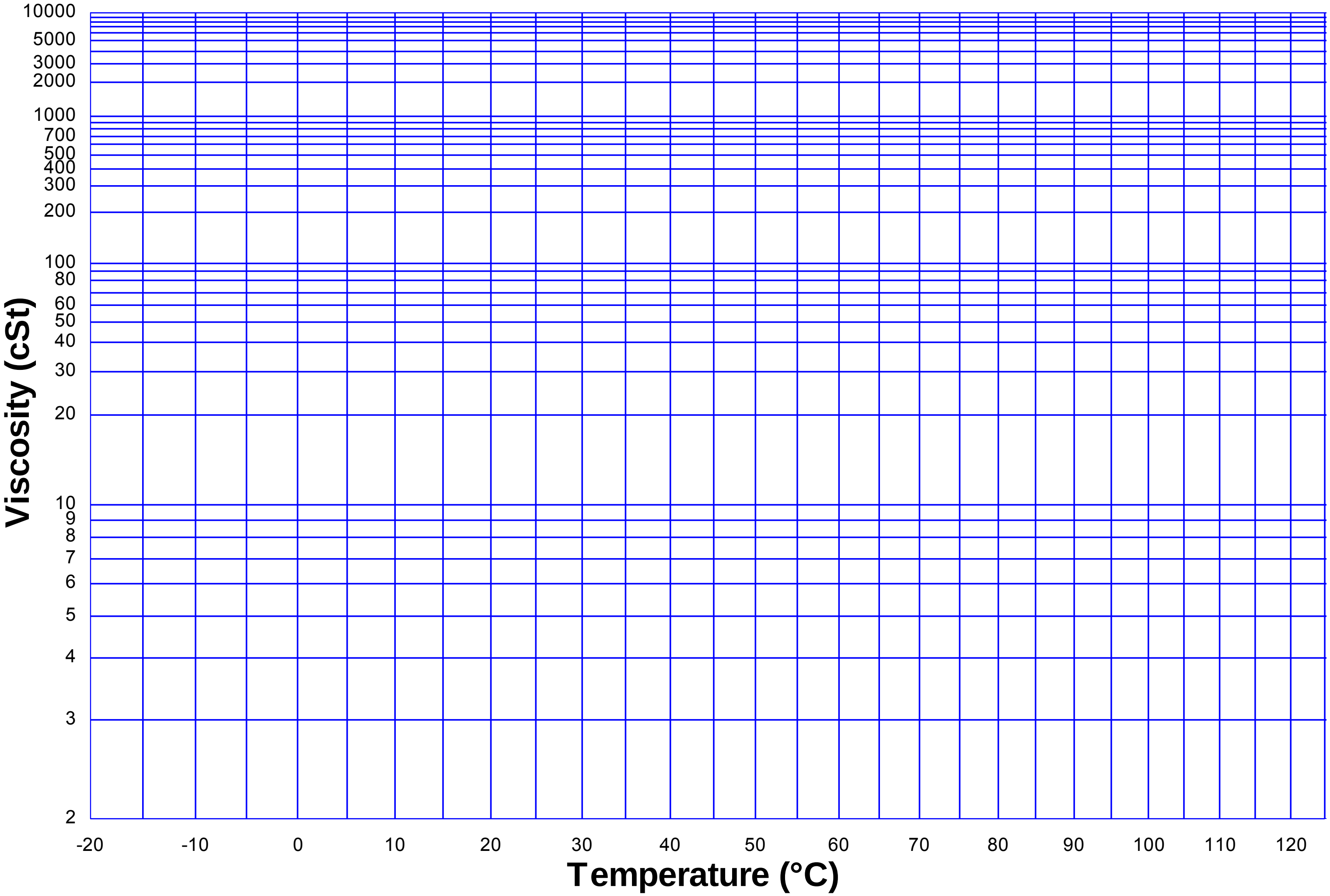
Why Estimate/Measure Mixture Viscosity?

- Refrigerant drastically cuts the lubricant viscosity
  - Primarily: Compressor Lubrication
  - Secondary:
    - Lubricating auxiliary valves and seals
    - Sealing microscopic leaks
  - Heat Exchanger / Piping Design Considerations
    - Heat transfer enhancement or fouling
      - Heat Exchanger length - Nu ~ *f*(Pr, Re,…)
    - Increased Pressure drop
      - Heat Exchanger circuiting or tube sizing - ΔP ~ *f*(Re,…)
    - Oil Management
      - Retention, “Hold-up” & Oil Return

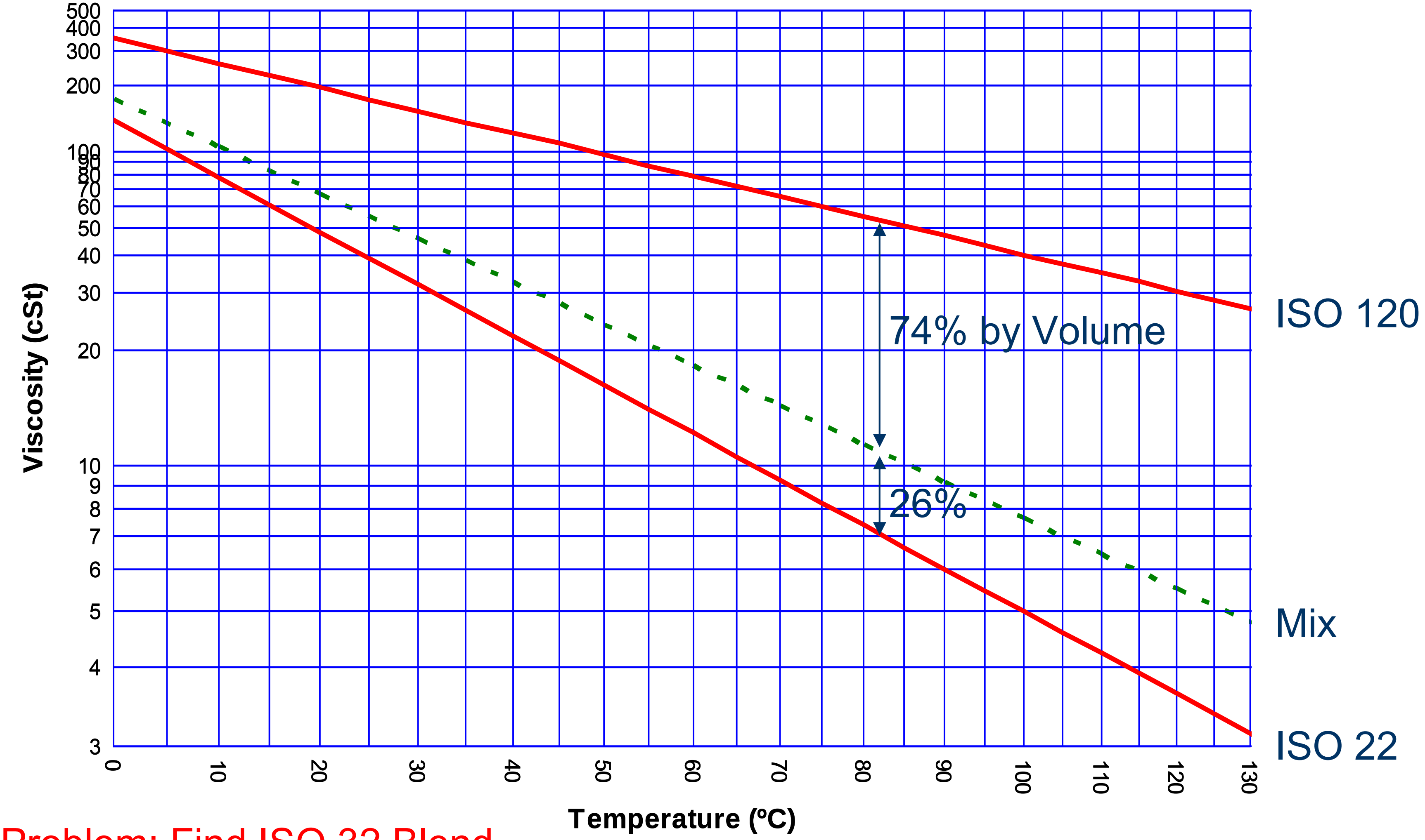
$$\mathrm{Re} = \left(\frac{\vec{V}D}{\nu} \right)$$

Viscosity – Temperature Chart



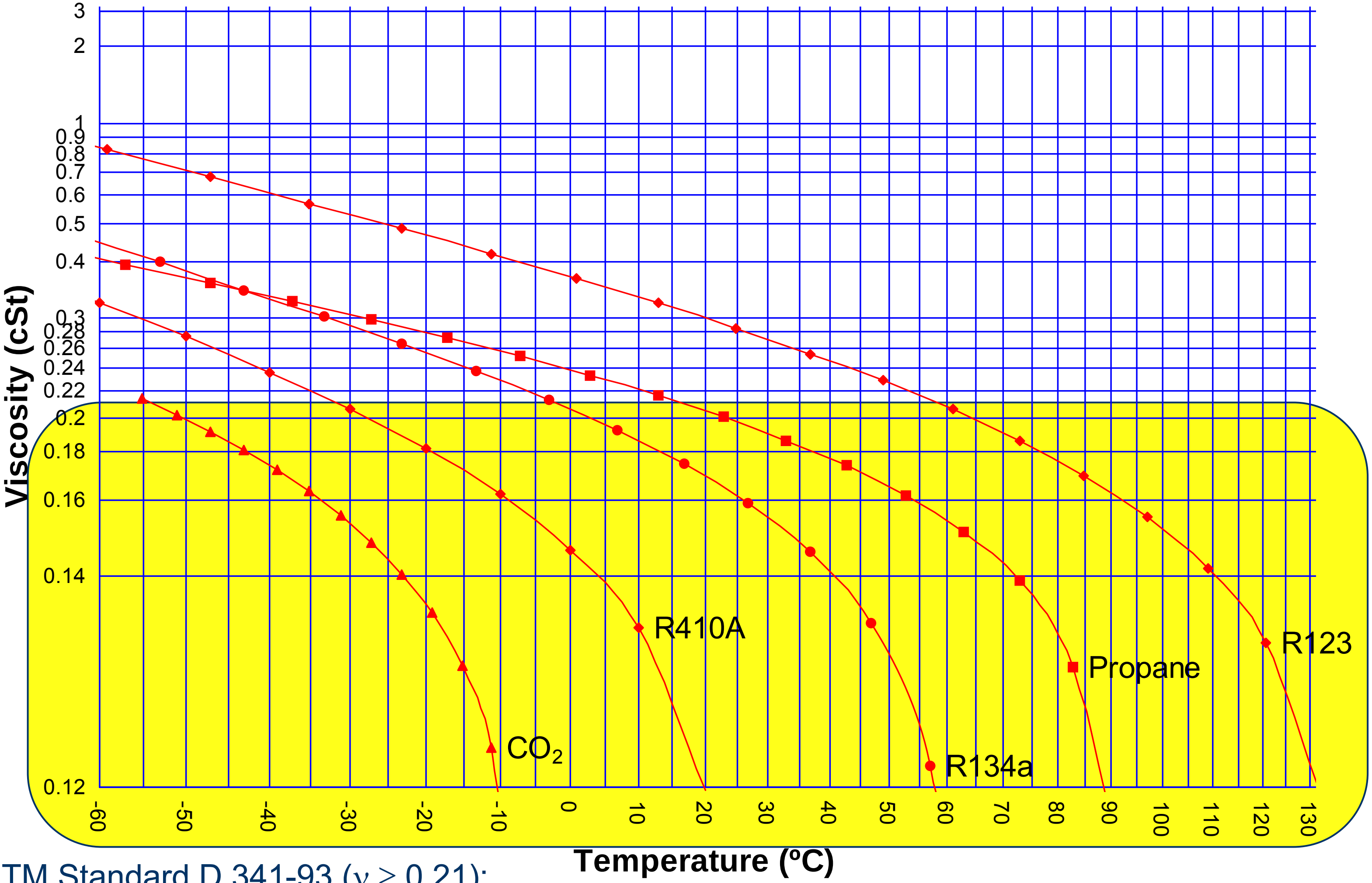
ASTM Standard D341-93 (1998)

Historical Lubricant Blending



Problem: Find ISO 32 Blend

ASTM Chart – Application to Refrigerants



ASTM Standard D 341-93 ($\nu \geq 0.21$);
Manning equation ($\nu < 0.21$)

2006 Refrigeration Handbook, Chapter 7

- Relationship between temperature and kinematic viscosity (ASTM D341)

$$Log_{10}\left(Log_{10}\left(\nu+0.7+f_{ASTM}\left(\nu\right)\right)\right)=A-B*Log_{10}\left(T\right)$$

$$f_{ASTM}\left(\nu\right)=C-D+E-F+G-H$$

$$C=\exp\left(-1.14883-2.65868\nu\right) \quad ; \quad D=\exp\left(-0.00381308-12.5645\nu\right)$$

$$E=\exp\left(5.46491-37.6289\nu\right) \quad ; \quad F=\exp\left(13.0458-74.6851\nu\right)$$

$$G=\exp\left(37.4619-192.643\nu\right) \quad ; \quad H=\exp\left(80.4945-400.468\nu\right)$$

- Undefined below 0.21 cSt!

Criteria for a new Viscosity-Temperature Chart

It is desired to construct a generalized chart that is able to:

- Cover entire temperature range (cryogenic to high temperatures)
- Cover entire viscosity range (~0.04 cSt to glass transition)
- Linearize fluids that do not exhibit excessive molecular coiling, molecular bonding, or wax precipitation
- Maintain the existing ASTM format for lubricants for viscosities greater than 2 cSt.
- Provide blending of lubricant and refrigerant mixtures

New Scaling Rule

$$Log_e\left(Log_e\left(\nu+0.7+f_{CS}(\nu)\right)\right)=A-B*Log_e(T)$$

$$f_{CS}(\nu)=e^{-\nu}K_0(\nu+\psi)$$

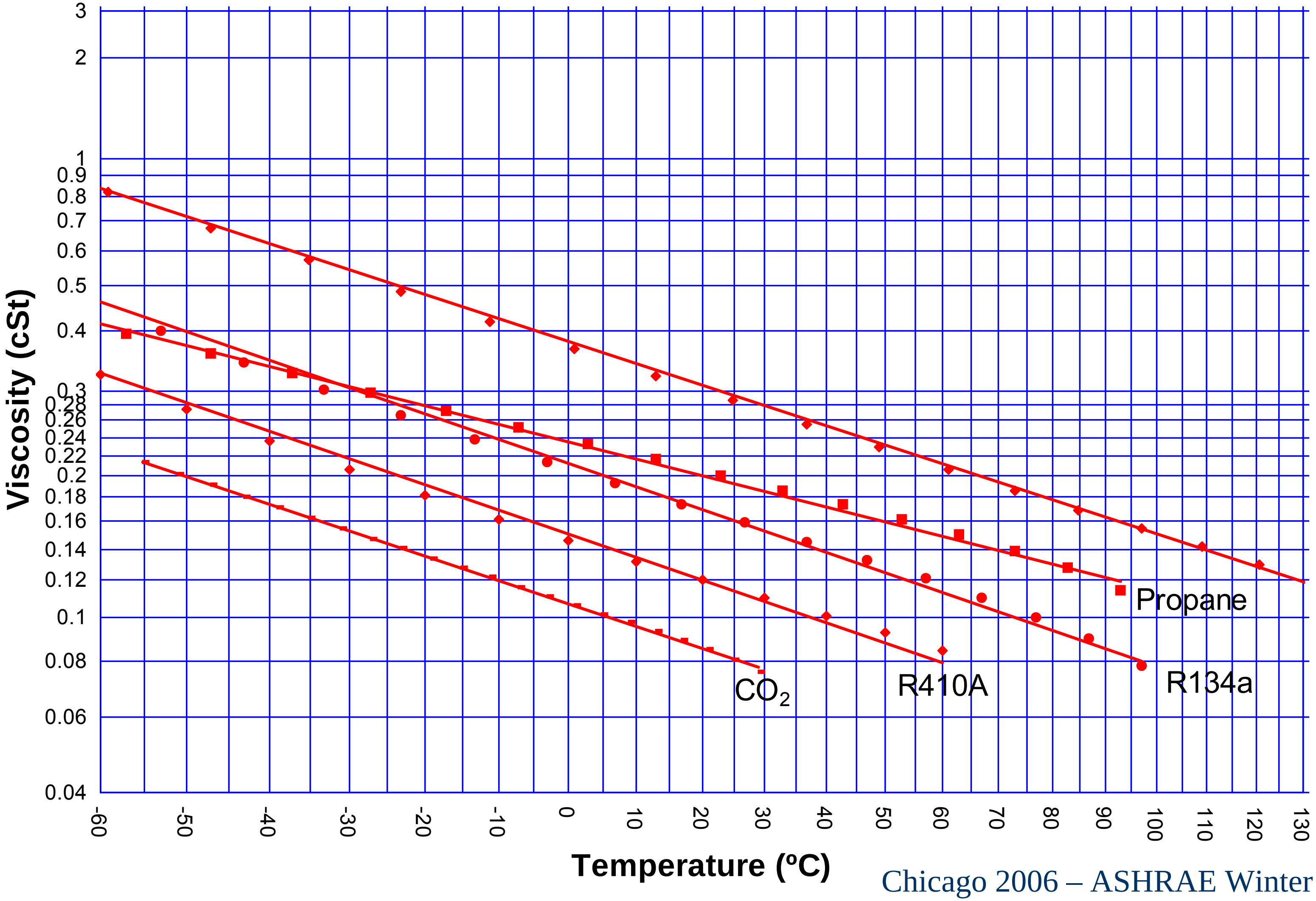
- Scaling the LHS to approach -infinity as $\nu \rightarrow 0$

$$\psi=1.244\,067$$

$$Log_e\left(Log_e\left(\nu+0.7+e^{-\nu}K_0(\nu+1.244067)\right)\right)=A-B*Log_e(T)$$

$$y=mx+b$$

New Viscosity Chart



ASTM Blending Rule

- Volume based blending rule

$$Log_{10}\left(Log_{10}\left(\nu_{mix}+0.7+f_{ASTM}\left(\nu_{mix}\right)\right)\right)=\sum V_i*\left(A_i-B_i*Log_{10}\left(T\right)\right)$$

$$V_i=\frac{Vol_i}{Vol_{total}} \qquad Vol_{total}=\sum Vol_i$$

$$y_{mix}=\sum V_i*\left(A_i-B_i*Log_{10}\left(T\right)\right)$$

For lubricants only, accuracy is generally better than ±15%

Estimation depends on prior knowledge

- Assume density of fluids and their mixture are equal

Volume fraction = Mass Fraction

$$V_i = w_i$$

$$y_{mix} = \sum w_i * \left(A_i - B_i * Log_e \left(T \right) \right)$$

For refrigerant/lubricant mixtures, accuracy is generally better than ±20%

Estimation depends on prior knowledge

- Recognize that the density of individual fluids are different, but they mix ideally

$$V_i = \frac{Vol_i}{Vol_{total}} = w_i \frac{\rho_{mix}(T)}{\rho_i(T)} \qquad \rho_{mix}(T) = \left(\sum \frac{w_i}{\rho_i(T)} \right)^{-1}$$

$$y_{mix} = \sum_i w_i \frac{\rho_{mix}(T)}{\rho_i(T)} * \left(A_i - B_i * Log_e(T) \right)$$

For refrigerant/lubricant mixtures, accuracy is generally better than ±15%

Estimation depends on prior knowledge

- If measured data is available…

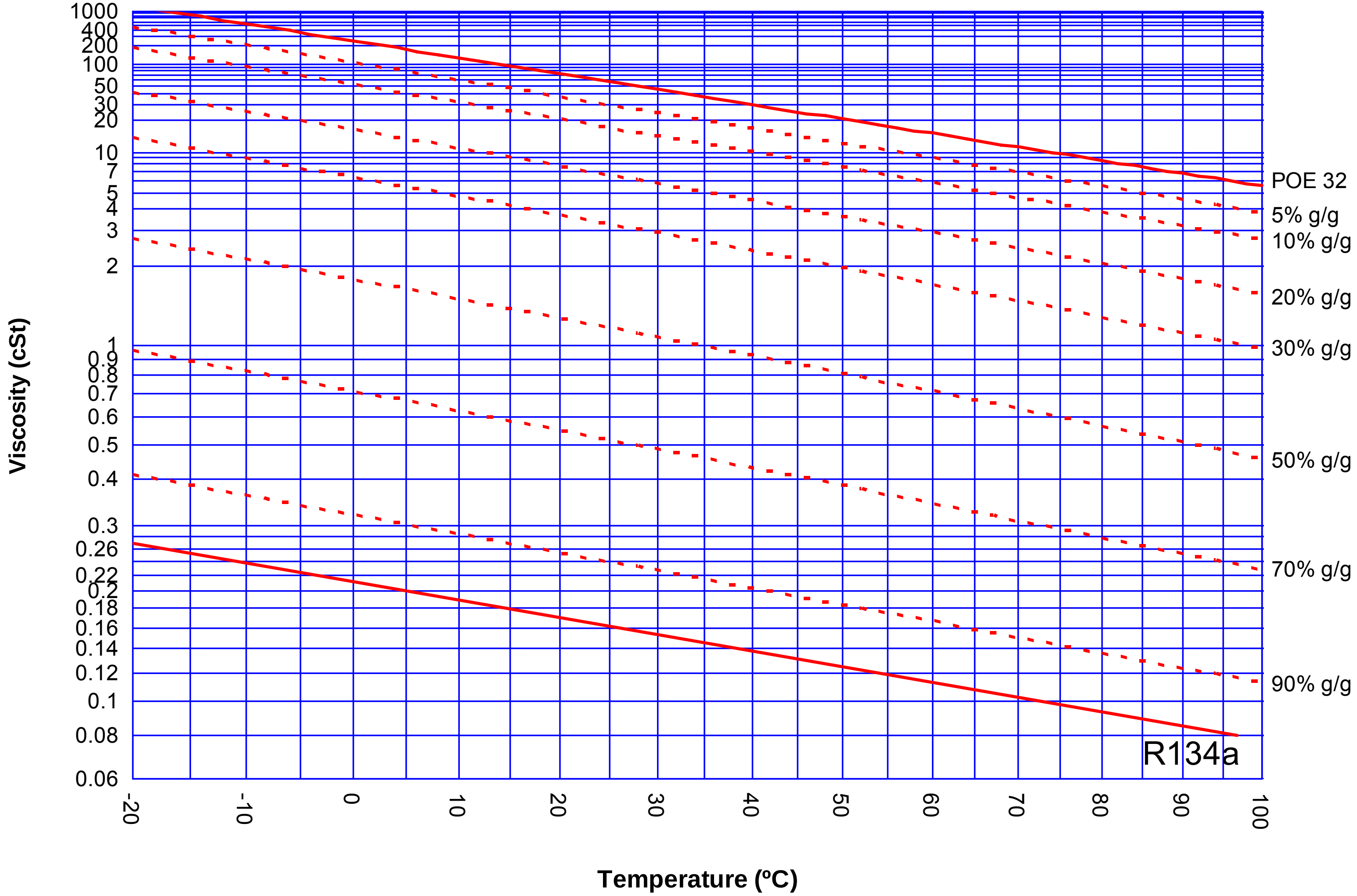
$$y_{mix}=\sum_i\left(\left(1+\sum_j \varphi_{ij}w_iw_j\right)*w_i\frac{\rho_{mix}(T)}{\rho_i(T)}*\left(A_i-B_i*Log_e(T)\right)\right)$$

$$\varphi_{ij}=\varphi_{ji}\quad;\quad\varphi_{ii}=\varphi_{jj}=0$$

$$\varphi_{ij}=f(T,w)$$

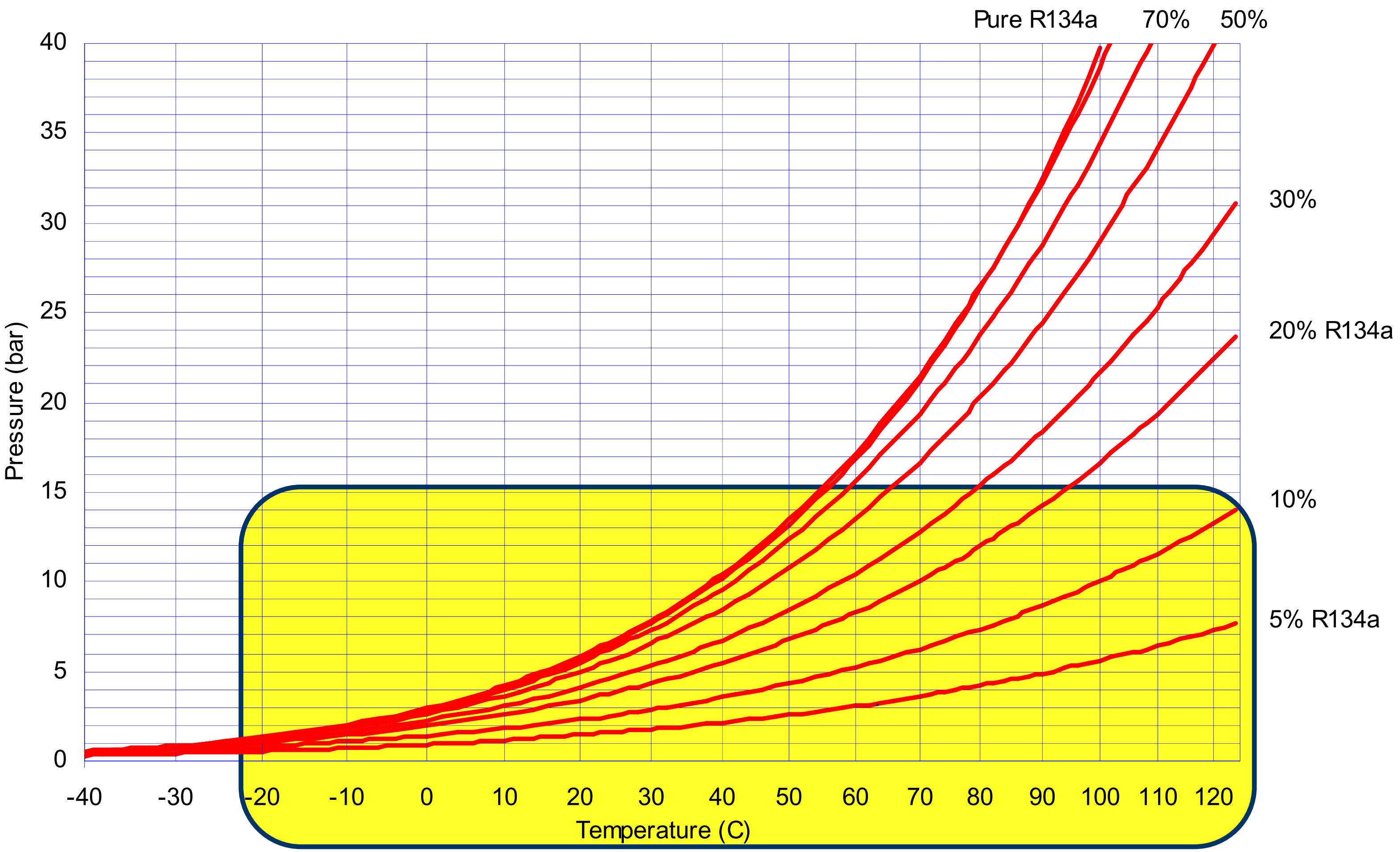
Accuracy is greatly enhanced ~ ±2%

Viscosity Prediction – POE + R134a

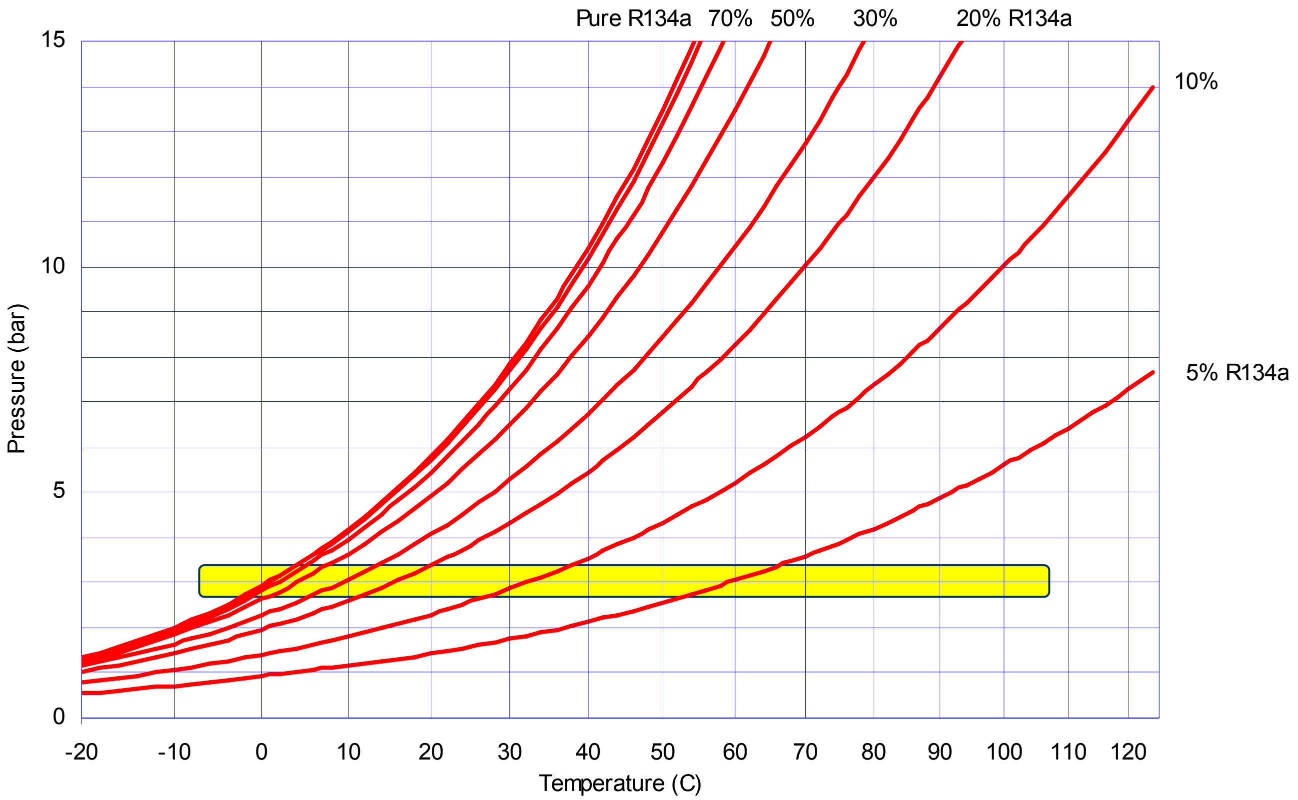


Basic Solubility Measurement

Results of Solubility Measurements



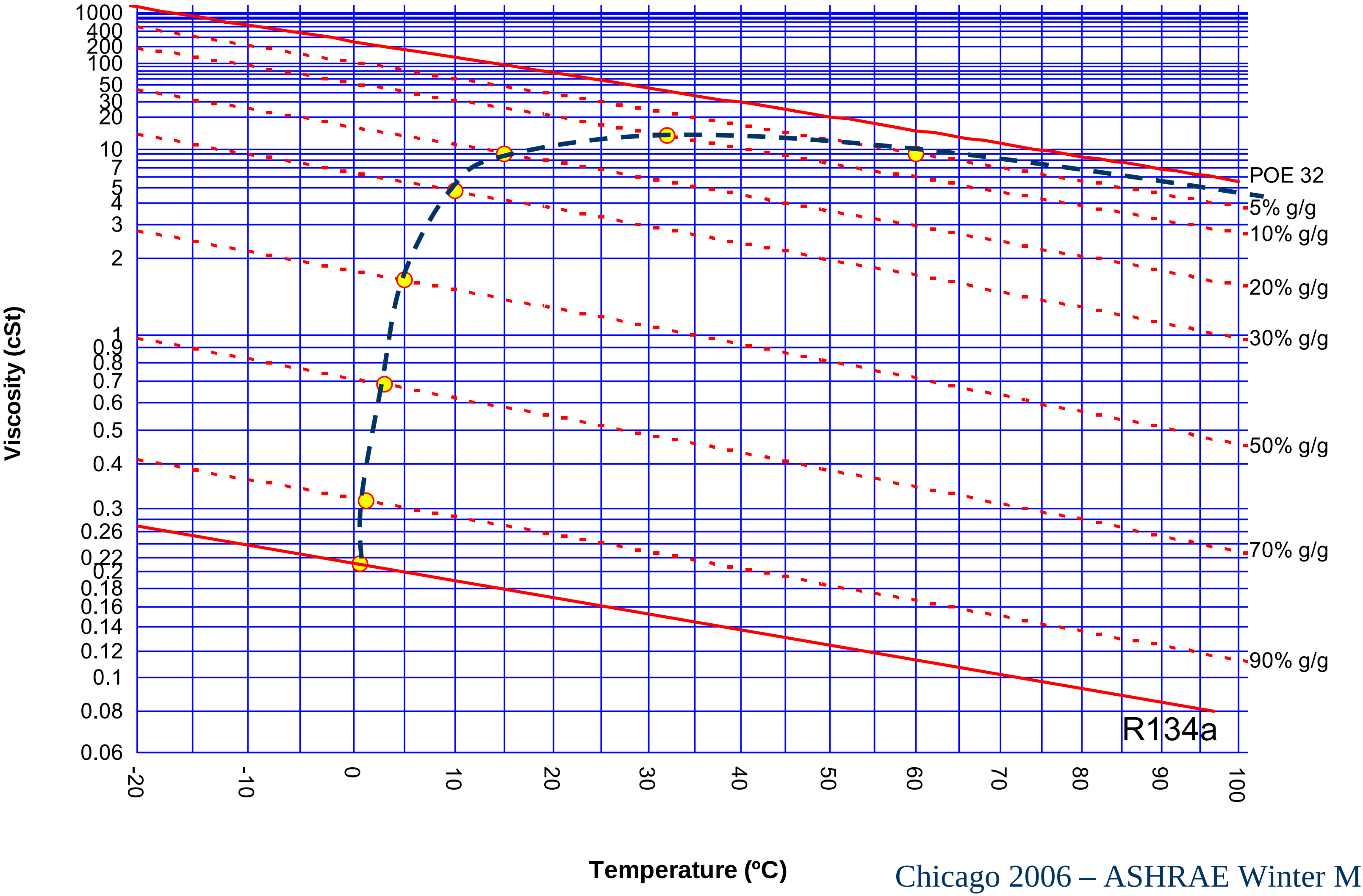
Results of Solubility Measurements



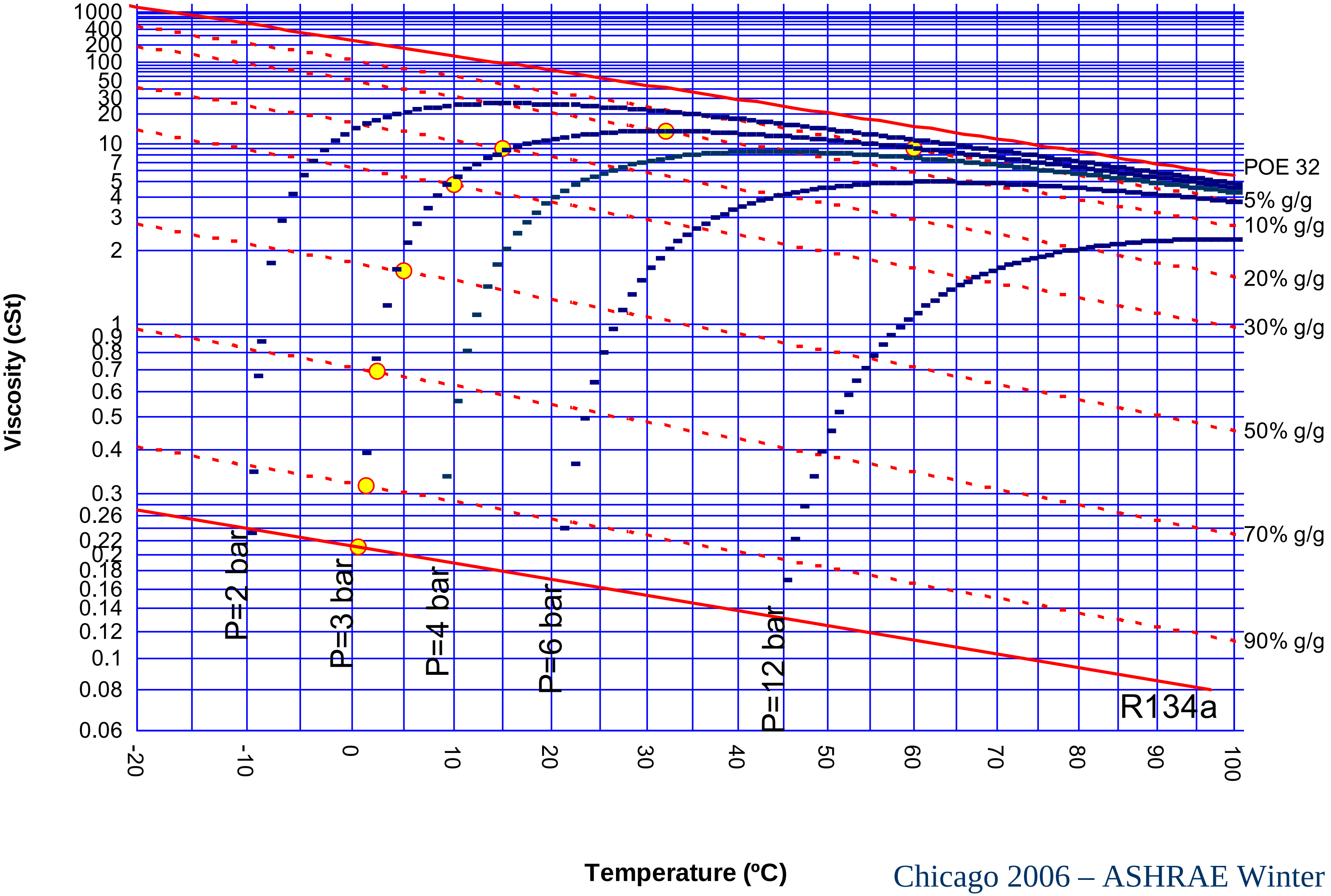
Pressure = 3 bar

Conc. % R134a	Temp. °C
5%	60
10%	32
20%	15
30%	10
50%	5
70%	2.5
90%	1.3
100%	0.67

Constant Pressure Curves

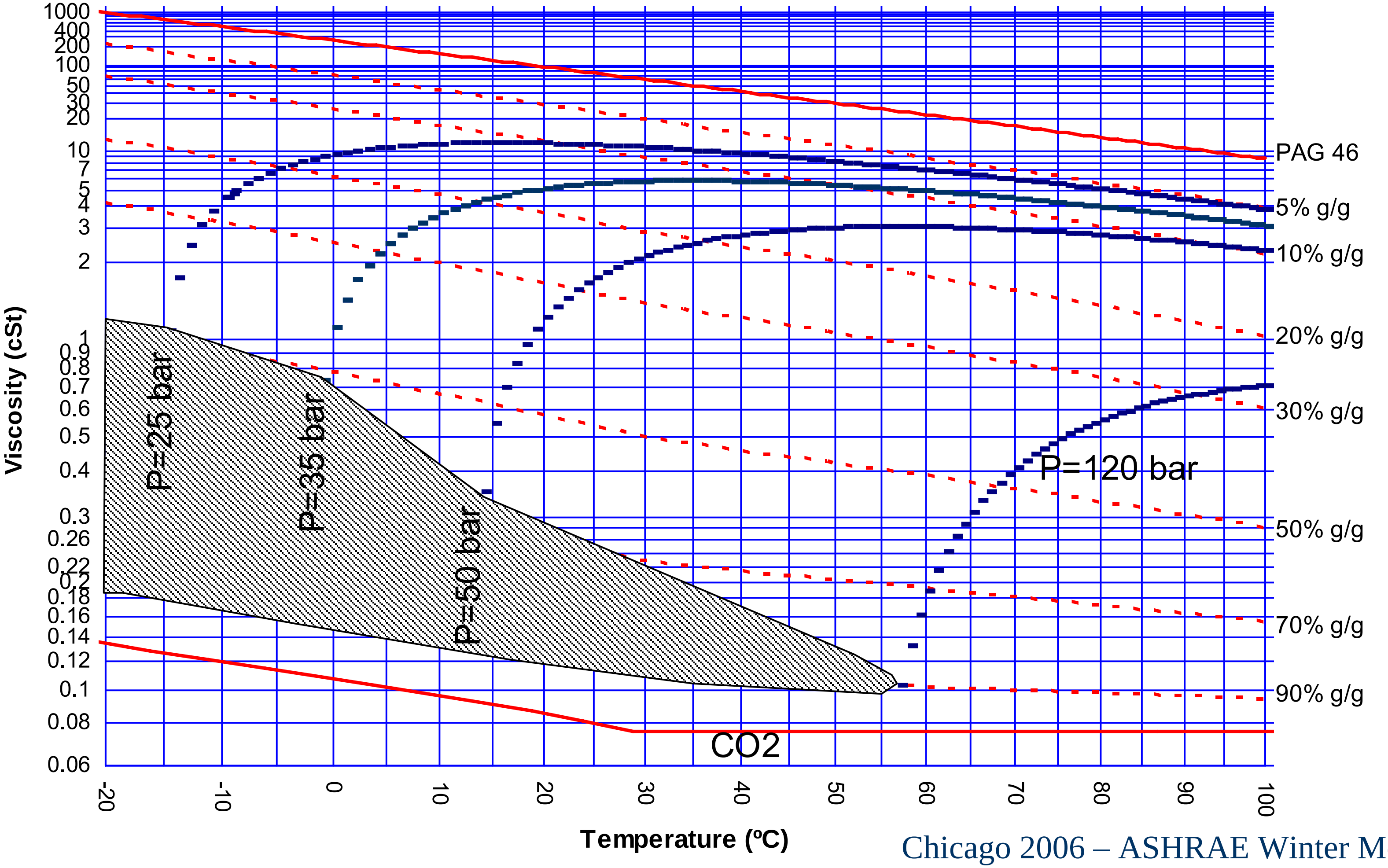


Daniel Chart – POE32 / R-134a



Real Motivation - CO_2

Estimated viscosity does not represent experimental measurements!



Conclusions

- Refrigerant – lubricant mixture viscosities can be estimated
- HFCs and hydrocarbons behave well on the proposed chart
- CO_2 does not mix ideally.
  - A new mixing rule is under development.
  - Experimental data is required!
    - Pressures must be over 35 bar (500 psia) to capture “in operation” conditions for air conditioning