Lubricants for synthetic and natural refrigerants: effects on system efficiency

Claudio Zilio
Università di Padova - Dipartimento di Fisica Tecnica
Via Venezia, 1, I-35100 Padova – Italy

Sergio Bobbo
CNR-ITC
c.so Stai Uniti, 4, I-35100 Padova - Italy

XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

Presentation outline:

- **Solubility and miscibility issues of lubricants with carbon dioxide**
- **Needs for a "comprehensive thermodynamic approach"**
- **Recent investigations on lubricant effects in evaporators and condensers**

XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

Refrigerant compressor lubricant

A lubricant should answer to some criteria to be suitable to use in refrigerant cycle with vapor compression. :

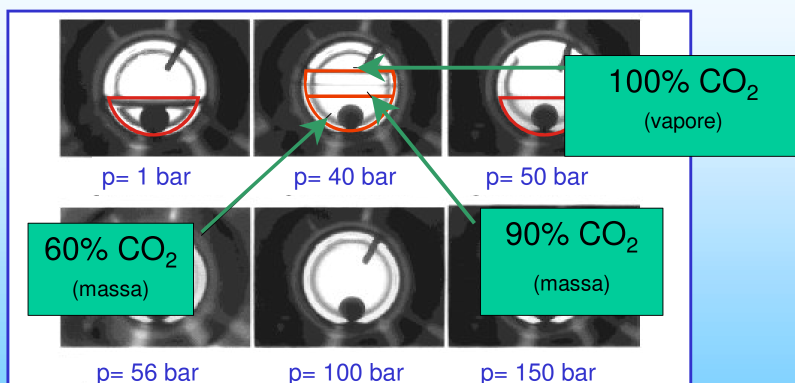
-characteristics of lubrication of the compressor (solubility viscosity)

-appropriate behavior for the return to the compressor (miscibility)

-stability and compatibility with other materials used

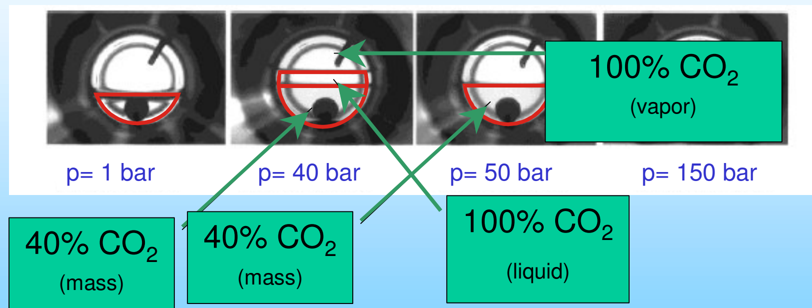
XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

VLE and LLE equilibria of the system POE-CO_2 T=5°C



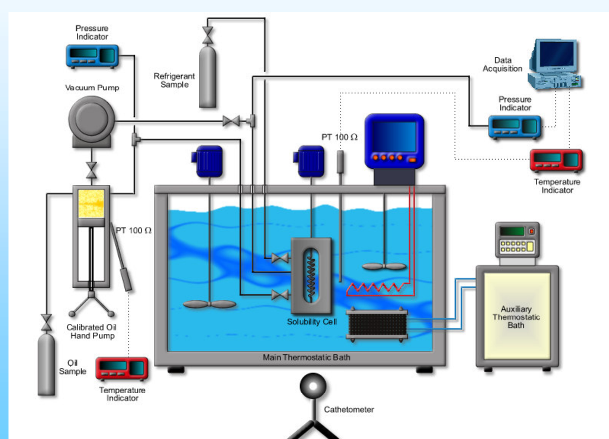
Alexander Hauk and Eckhard Weidner
Thermodynamic and Fluid-Dynamic Properties of Carbon Dioxide with Different Lubricants in Cooling Circuits for Automobile Application
Ind. Eng. Chem. Res. **2000,** *39,* 4646-4651

VLE and LLE equilibria of the system PAG-CO_2 T=5°C



XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

Phase equilibrium of CO_2-lubricant mixtures: text rig in CNR-ITC

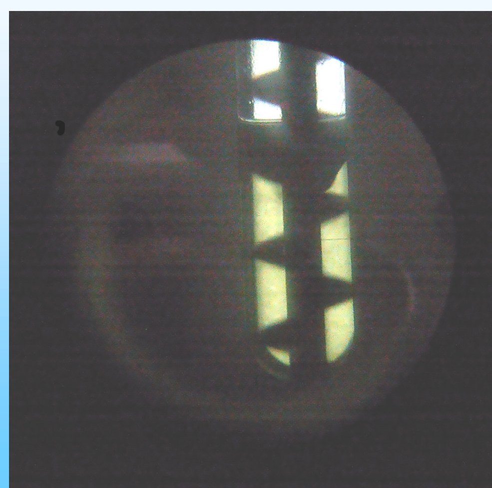


XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

Phase equilibrium of CO_2-lubricant mixtures: text rig in CNR-ITC

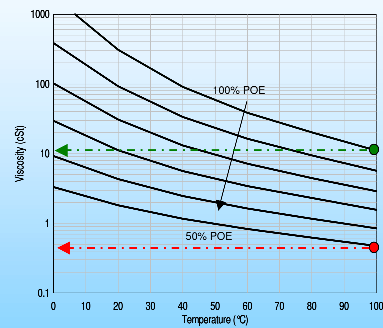
XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

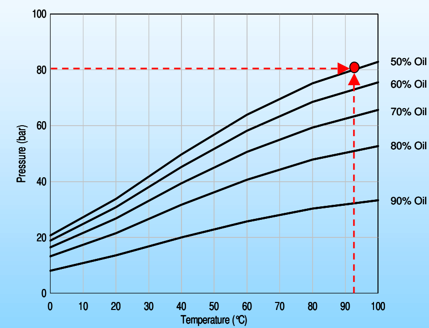
Phase equilibrium of CO_2-lubricant mixtures: text rig in CNR-ITC



XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

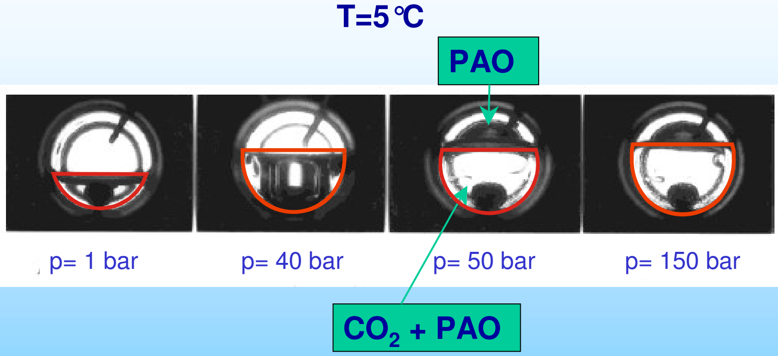
Phase equilibrium and viscosity for the system POE 100-CO_2





XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

VLE and LLE equilibria for the system PAO-CO_2
T=5°C



There is need for a "Comprehensive Thermodynamic Approach" to modelling refrigerant –lubricant mixtures (J. Thome, 1995)

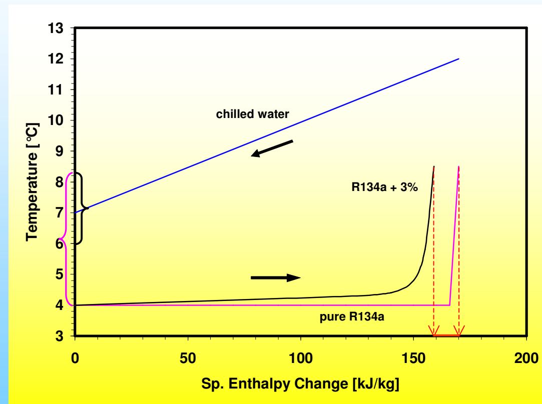
~~Old "Oil contamination approach"~~

New approach: Oil-refrigerant system as a zeotropic mixture with bubble point temp., local oil concentrations, modified liquid specific heat and enthalpy changes during thermodynamic transformations.

Effects of lubricant in heat exchangers

- **Modified LMTD (Log Mean Temperature Difference)**
- **Modified HTC (Heat transfer coefficient)**
- **Modified pressure drops**
- **The major effect is on EVAPORATOR**

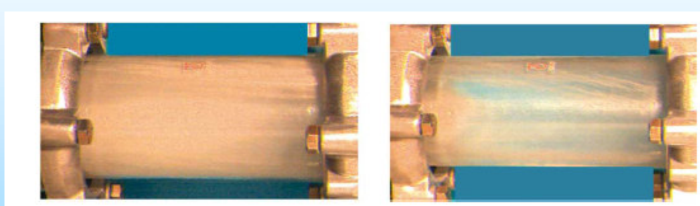
Effects on evaporator: LMTD and vapor superheat



Lower sp. Enthalpy change – "Apparent superheat"

Effects on evaporator: "apparent superheat"

Visualization of the liquid phase at the evaporator outlet



ΔT=2 K **ΔT=10 K**

Apparent superheat

Note: same amount of oil circulating in both pictures

The picture is taken from:
M. Youbi-Idrissi, J. Bonjour, M.-F. Terrier, C. Marvillet, F. Meunier
Oil presence in an evaporator: experimental validation of a refrigerant/oil mixture enthalpy calculation model
Int. J. Refrigeration. **2004**, *27,* 215-224

Effects on boiling heat transfer coefficients: R134a-POE (DE589) pool boiling on plain roughened copper surface (1)

- Kedzierski (2005) recent study with spectrofluorometric technique.
- The lubricant is preferentially drawn out of the bulk oil/refrigerant mixture by the boiling process and accumulates on the surface in excess of the bulk concentration.
- Measurements indicate that an approx. 40 µm oil layer is created.
- Three different mass concentration were considered for the DE589 POE lubricant: 0.5%, 1%, 2%.

XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

Effects on boiling heat transfer coefficients: R134a-POE (DE589) pool boiling on plain roughened copper surface (2)

q''_p: pure R134a heat flux

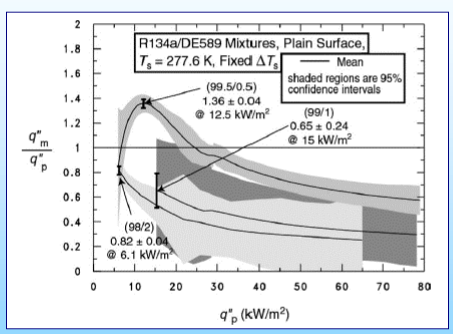
q''_m: R134a-POE heat flux

T_s= 277.6 K liquid saturation temperature of the R134a-POE mixture

Tw: wall temperature

$\Delta T_s = T_w - T_s$ wall superheat

$q''_m/q''_p > 1$ indicates heat transfer enhancement



R134a-POE (99.5/0.5) shows a heat transfer enhancement for q''_m between 5 and 20 kW/m^2

The graph is taken from:
M. A. Kedzierski
Effect of bulk lubricant concentration on the excess surface density during R134a pool boiling
Int. J. Refrigeration. **2005**, *28*, 526-537

XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

Effects of lubricant during in-tube condensers (1)

•Bassi and Bansal (2003): R134a-POE condensing at T_{sat} between 35 and 45 °C. Internal condensation HTC reduces by 5% (R134a-POE 98/2 in mass) and by 10% (R134a-POE 95/5 in mass).

•Infante Ferreira et al. (2003): R404A-POE (0 to 4% oil concentration) condensing at T_s= 40°C inside smooth, microfin and cross-hatched horizontal tubes. Up to 2% oil mass concentration, lubricant slightly increases heat transfer for enhanced surfaces. Oil higher concentration penalizes HTC especially at high mass flux.

•Marked effect of pressure drops: 4% oil mass concentration causes up to 25% pressure drop increment

XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

Effects of lubricant during in-tube condensers (2)

•Eckels and Holthaus (2004): Results of ASHRAE project RP-1067

•R134a, R407C, R410A with POE and R22 with mineral oil (0 to 5% oil mass concentration) superheated vapor heat transfer and pressure drop in smooth tubes with 6.5 and 8 mm ID. Test pressure equivalent to 40°C saturation.

•The addition of lubricant always increases the HTC up to 40% for all oil concentrations.

•Astonishing effect on pressure drops: increase up to 300% for Re_g=300000 and up to 200% for Re_g=600000.

Open question: effects of lubricant in aluminium minichannel evaporator and condensers (HTC and pressure drop): very poor experimental data

CONCLUSIONS

•A thermodynamic approach is needed for the modelling of lubricant effects mainly for the optimisation of the heat transfer in a vapor cycle system operating machine and for improving control strategies.

•A fundamental step towards this “thermodynamic approach” is linked to the availability of full sets of solubility data for different refrigerants and lubricant types.

•Further experimental and theoretical investigations are needed to fill the lack of data about lubricants effects on HTC and pressure drops of refrigerant-oil mixtures.

XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

Cited literature

J. R. Thome, Comprehensive thermodynamic approach to modeling refrigerant-lubricating oil mixtures, *HVAC&R Research.* **1995**, *1,* 110-126

M. A. Kedzierski, Effect of bulk lubricant concentration on the excess surface density during R134a pool boiling *Int. J. Refrigeration.* **2005**, *28,* 526-537

M. Youbi-Idrissi, J. Bonjour, M.-F. Terrier, C. Marvillet, F. Meunier, Oil presence in an evaporator: experimental validation of a refrigerant/oil mixture enthalpy calculation model. *Int. J. Refrigeration.* **2004**, *27,* 215-224

C. A. Infante Ferreira, T. A. Newell, J. C. Chato, X. Nan, R404A condensing under forced flow conditions inside smooth, microfin and cross-hatched horizontal tubes. *Int. J. Refrigeration.* **2003**, *26,* 433-441

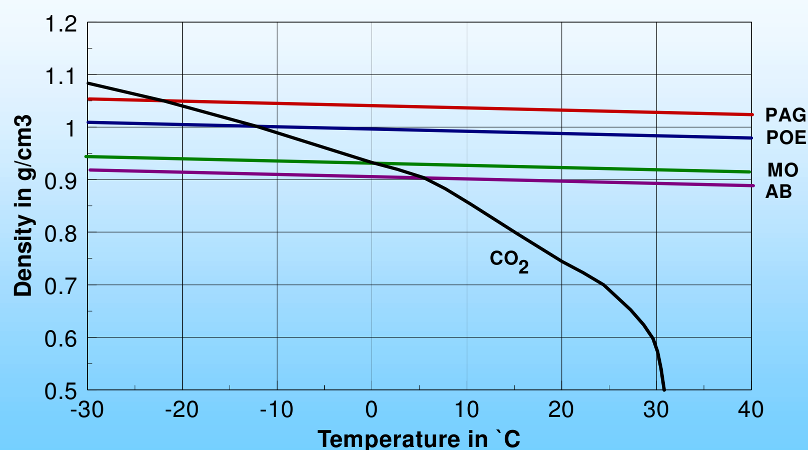
S. J. Eckels, G. D. Holthaus, Single-phase heat transfer and pressure drop performance in smooth tubes with R-22, R-134a, R-407C, and R-410a at superheated conditions with lubricant mixtures (RP-1067), *HVAC&R Research.* **2004**, *10,* 421-439

XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

Thank you!

XI European Conference on Refrigeration and Air Conditioning
Milan, June 17th and 18th, 2005

Phase-inversion phenomenon



PAO density < 850 kg/m^3