INTERNATIONAL JOURNAL OF REFRIGERATION 31 (2008) 34–44

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journal homepage: www.elsevier.com/locate/ijrefrig

Solubility, density and viscosity of a mixture of R-600a and polyol ester oil

Moisés A. Marcelino Neto, Jader R. Barbosa*

Department of Mechanical Engineering, Federal University of Santa Catarina, Florianópolis, SC 88040-900, Brazil

A R T I C L E I N F O

Article history:
Received 6 February 2007
Received in revised form
31 July 2007
Accepted 6 August 2007
Published online 19 August 2007

Keywords:
Refrigerant
Isobutane
R-600a
Measurement
Solubility
Density
Viscosity
Binary mixture
Polyolester

A B S T R A C T

Experimental data on solubility, liquid phase density and viscosity of a mixture of R-600a and a POE ISO 7 lubricant oil are presented. A specially designed experimental facility for simultaneous measurements of the physical properties was used in the experiments at temperatures ranging from 10 to 60 °C. The VLE data were correlated with the Heil–Prausnitz and Flory–Huggins activity models and the Peng–Robinson equation of state (EoS). Liquid density was correlated with the Peng–Robinson EoS and with a first-order Redlich–Kister expansion for the excess molar volume. Liquid viscosity was correlated with an excess-property approach based on the classical Eyring liquid viscosity model. Satisfactory agreement was obtained between models and experiments; maximum root mean square (RMS) deviations of models used in the VLE, density and viscosity predictions were 1.1% (VLE EoS), 0.2% (Redlich–Kister) and 3.0% (Grunberg–Nissan), respectively.

Solubilité, densité et viscosité d’un mélange de R-600a et de l’huile polyolester

Mots clés : Frigorigène ; Isobutane ; R-600a ; Mesure ; Solubilité ; Densité ; Viscosité ; Mélange binaire ; Polyolester

1. Introduction

Isobutane (R-600a) is widely used as a refrigerant in low capacity (household and small commercial) refrigeration applications. According to Billiard (2003), in 2000, R-600a systems represented 21% of the total world production of domestic refrigerators. Because of their many advantages, such as zero Ozone Depletion Potential (ODP), low Global Warming Potential (GWP), low cost and improved cycle performance at high condensing temperatures, R-600a and other hydrocarbon

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* *Corresponding author*. Tel./fax: +55 48 3234 5166.
E-mail address: jrb@polo.ufsc.br (J.R. Barbosa Jr.).

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doi:10.1016/j.ijrefrig.2007.08.004

Nomenclature

Roman

$a(T)$	molecular attraction parameter (J m^3 mol^{-2})
b	molecular repulsion parameter (m^3 mol^{-1})
c	volume molar correction (–)
D	adjusted parameter in the Redlich–Kister expansion (J kmol^{-1})
h	Planck's constant [6.626×10^{-34}] (J s)
m_R	mass of refrigerant in the liquid sample (kg)
m_O	mass of oil in the liquid sample (kg)
N_a	Avogadro's number [6.023×10^{26}] (kmol^{-1})
$\hat{f}_i^k$	fugacity of component i in phase k (Pa)
f_i^0	fugacity of component i in the standard state (Pa)
G^+	activation energy for viscous flow (J kmol^{-1})
G^{E+}	excess activation energy for viscous flow (J kmol^{-1})
k_{ij}	molecular interaction parameter in the Peng–Robinson EoS (–)
M	molecular mass (kg kmol^{-1})
P	pressure (Pa)
Pe	Poynting factor (–)
P_c	critical pressure (Pa)
R	gas constant [~8314.51] (J kmol^{-1} K^{-1})
T	temperature (K, °C)
T_c	critical temperature (K, °C)
T_R	reduced temperature [T/T_C] (–)
x_i	liquid mass fraction (solubility) of component i (–)
$\bar{x}_i$	liquid mole fraction of component i (–)
V	molar volume (m^3 kmol^{-1})
V'	molar volume (translation correction) (m^3 kmol^{-1})
y_i	vapour mass fraction of component i (–)
$\bar{y}_i$	vapour mole fraction of component i (–)
Z	compressibility factor (–)

Greek

χ	Flory parameter (–)
Φ	fugacity coefficient (–)
γ	activity coefficient (–)
η	dynamic viscosity (kg m^{-1} s^{-1})
λ_{ij}	interaction parameter in the Heil–Prausnitz model (–)
Λ_{ij}	binary parameter (Heil–Prausnitz model) (–)
Θ	volume fraction (–)
ρ	density (kg m^{-3})
ω	acentric factor (–)

Superscripts

E	excess property
id	ideal
k	phase k
L	liquid
sat	saturation
V	vapour

Subscripts

C	critical
cal	calculated
exp	experimental
i	component i
j	component j

refrigerants are regarded as viable alternatives in a global scenario where more stringent environmental legislation is applied (Haukas, 1999).

In refrigeration compressors, the thermophysical properties of the lubricant are strongly affected by the intense mixing between oil and refrigerant. For instance, because of the large difference between the viscosity of pure oil and liquid refrigerant, even small amounts of refrigerant dissolved in the oil may hamper compressor lubrication and hence reduce its life span and reliability.

Another important feature of refrigerant–oil mixing is related to the determination of the equalizing pressure, i.e., the pressure attained by the system while the compressor is off. In small systems, refrigeration capacity control is performed by a succession of on–off compressor cycles. During each cycle, immediately after the compressor turns off, a process of absorption of the vapour refrigerant in the oil inside the compressor shell is initiated. In reciprocating compressors, high refrigerant absorption rates (that depend on thermodynamic and heat and mass transport aspects of the oil and refrigerant mixture) are desirable since lower equalizing pressure means reduced torque and power required for compressor start-up.

Despite the abundant literature on phase equilibrium and physical properties of mixtures of oil and halocarbon refrigerants mixtures (Glova, 1984; van Gaalen et al., 1990, 1991a,b; Corr et al., 1993; Grebner and Crawford, 1993; Martz and Jacobi, 1994; Takaishi et al., 1994; Cavestri, 1995; Martz et al., 1996; De Andrade et al., 1999; Jeng et al., 2001; Yokozeki et al., 2000, 2002; Youbi-Idrissi et al., 2004; Park et al., 2004; Tesser et al., 1999, 2004; Michels and Sienel, 1995; Burton et al., 1999; Marsh and Kandil, 2002; Wahlström and Vamling, 2000; Yokozeki, 2001; Fleming and Yan, 2003; Guillemet and Lottin, 2004), there is a lack of studies dealing specifically with R-600a/oil mixtures. Spauschus et al. (1994) presented solubility and viscosity data for mixtures of mineral and synthetic oils with R-290 (propane) and R-600a. They observed limited solubility of both refrigerants in a polyalkylene glycol oil (PAG ISO 100) at temperatures between 30 and 100 °C. The solubility in a polyol ester oil (POE ISO 120) was higher than in the PAG lubricant, but lower than in mineral (MN ISO 46 and ISO 114) and alkyl benzene (AB ISO 100) oils. More recently, Zhelezny et al. (2007) measured the solubility, density and capillary constant of a mixture of R-600a and mineral oil Azmol for temperatures between 30 and 90 °C. They pointed out the importance of taking into account the difference in composition between the bulk liquid phase and the surface layer in the development of thermodynamic models for calculating physical properties.

Randles et al. (2003) analysed the many issues associated with the use of mineral and synthetic oils with R-600a and R-290. In general, the high solubility of these refrigerants in mineral oils can lead to foaming, wear problems and high oil carryover. Foaming and wear can be treated conventionally with anti-foaming and anti-wear oil additives. However, excessive oil carryover has led to oil slugging issues in certain systems and this can markedly reduce energy efficiency over