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R1234yf as a substitute of R134a in automotive air conditioning. Solubility measurements in two commercial PAG oils

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ABSTRACT

Starting from January 1st 2011, as stated by the Directive 2006/40/EC, fluorinated greenhouse gases with a global warming potential (GWP) higher than 150 can not be used in automotive applications any more. For this reason, 1,1,1,2-tetrafluoroethane (R134a), commonly used for these applications, will be abandoned and substituted by refrigerants with lower GWP. In recent times, a new fluid, 2,3,3,3-tetrafluoroprop-1-ene (R1234yf) has been proposed as an interesting alternative, since it has a very low GWP and thermodynamic properties very similar to R134a. At the moment, only few data can be found on the thermodynamic properties of this new refrigerant and, in particular, its behaviour in solution with commonly used compressor lubricants is still to be evaluated. Here, solubility experimental data of R1234yf in a Polyalkylene Glycol (PAG) and in a specifically modified Double-Capped PAG (DC-PAG) commercial lubricants are measured with a static synthetic method at isothermal conditions, in the temperature range between 258 K and 338 K.

Le R1234yf comme substitut du R134a dans le conditionnement d'air automobile. Mesures de solubilité dans deux huiles PAG commerciales

Mots clés : 2,3,3,3-Tetrafluoroprop-1-ène (R1234yf) ; 1,1,1,2-Tetrafluoroéthane (R134a) ; Solubilité ; PAG Double-Couvert ; Polyalkylène glycol

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Nomenclature

P	pressure (MPa)
T	temperature (K)
ω	mass fraction of R1234yf in liquid phase (kg kg^{-1})

Subscripts

R134a	related to R134a

1. Introduction

On the base of the Directive 2006/40/EC, from January 1st 2011 "Member States shall no longer grant EC type-approval or national type-approval for a type of vehicle fitted with an air conditioning system designed to contain fluorinated greenhouse gases with a global warming potential (GWP) higher than 150". This means that R134a, the most used refrigerant for these applications to date, having a GWP (100 years) of 1430, will have to be abandoned as a working fluid for automotive air conditioning systems in favour of more environmentally benign refrigerants.

For such an application, a lot of research has been devoted in the last decade to carbon dioxide (CO_2), a natural refrigerant. However, its efficiency is relatively low and it requires a total redesign of the air conditioning system. More recently, a new refrigerant, 2,3,3,3-tetrafluoroprop-1-ene (R1234yf), has been proposed as a very promising alternative: it has a very low GWP (4 in a 100-year time horizon) (Nielsen et al., 2007) and thermodynamic properties as a drop-in substitute for R134a (SAE, 2009). The only drawback is a weak flammability.

Notwithstanding a large effort in automotive industry in the development of R1234yf in the past few years, thermodynamic and transport property experimental data and relative models and Equations of State (EoS) have begun to appear in the literature only from 2008. Up today, experimental data for R1234yf can be found on vapour pressure (Tanaka and Higashi, 2010; Di Nicola et al., 2010a; Hulse et al., 2009; Richter et al., 2011; Fedele et al., 2011), critical state properties (Spatz and Minor, 2008; Tanaka and Higashi, 2010), liquid density (Tanaka and Higashi, 2010; Hulse et al., 2009; Tanaka et al., 2010; Fedele et al., 2012), vapour phase density (Richter et al., 2010; Di Nicola et al., 2010b), specific heat at constant pressure (Tanaka et al., 2010), surface tension (Tanaka and Higashi, 2010), and liquid viscosity (Hulse et al., 2009). Moreover, some models have been presented, as Extended Corresponding States (ECS) EoS (Hulse et al., 2009; Akasaka et al., 2010), Martin-Hou (MH) EoS (Di Nicola et al., 2010b; Leck, 2009), Patel-Teja (PT) EoS (Akasaka et al., 2010), Peng-Robinson (PR) EoS (Brown et al., 2009, 2010), and Helmholtz EoS (Lemmon et al., 2007).

However, its behaviour in solution with commonly used compressor lubricants is still not well studied. Only few data on R1234yf miscibility with oils have been presented by Leck (2009), showing a partial immiscibility with POE lubricants. Moreover, Spatz (2009) presented a diagram showing the miscibility gap of some PAG lubricants (lower critical temperature as a function of lubricant mass fraction).

It is well known that some lubricant is discharged by the compressor, depending on the compressor characteristics and on the complex interaction between refrigerant and oil (including solubility). The ratio between the lubricant mass flow rate discharged by the compressor and the refrigerant mass flow rate is defined as the Oil Circulation Ratio (OCR). Depending on the circuit lay-out, the oil and the refrigerant type and the operating conditions, the discharged lubricant will distribute with different hold-up in each single component or line. The lubricant hold-up is considered to affect the efficiency of the refrigerating machine.

Different circuit arrangement, different refrigerant, different oil or different mass flow rate of the refrigerant itself may lead to completely different lubricant hold-up in each single component. It is a common belief that the compressor and circuit design should be carried out having the OCR reduction as a target.

Gordon et al. (2011) investigated the lubricant migration in automotive air conditioning applications both with R134a and R1234yf. They pointed out that the lubricant migration with R1234yf is still to be completely understood but surely affected by the refrigerant miscibility in the lubricant.

The lubricant type and the related OCR are fundamental for compressor efficiency and strongly affect also the two-phase heat transfer process inside circuit heat exchangers.

Shen and Groll (2005a,b) critically reviewed some of the most outstanding papers available in the open literature dealing with the effects of the lubricant mixed with the refrigerant on the heat transfer coefficient (HTC) and on pressure drop during the boiling process (2005a) and the condensation (2005b).

Both the mentioned works evidenced the high scattering of the experimental data available. The measurement presented by several Authors indicate every possible effect of the oil, both in the direction of a penalization, of an improvement and of a negligible effect of heat transfer, depending on the different testing conditions. Up to date, no systematic work dealing with the lubricant impact of HFOs heat transfer performance is available.

Zilio et al. (2011) showed how the miscibility gap of R1234yf in a PAG oil affects the thermal performance of a multiport minichannel condenser for automotive applications.

Hence, the knowledge of the lubricant/refrigerant solubility is a key factor for the performance and reliability of the refrigeration system. Unfortunately, it is not possible to find experimental measurements of R1234yf solubility in lubricant in the open literature. Much of the published work has been carried out in terms of R1234yf/lubricant stability by refrigerant producers (Spatz, 2009, among others), organizations (SAE through CRP-1234yf and JAMA, see for example Ikegami et al. (2008) and more recently AHRTI (2012)), lubricants producers (Dixon, 2010) or MAC systems manufacturers.

Here, solubility data in terms of pressure as a function of R1234yf mass fraction (ω) in a commercial double capped Polyalkylene Glycol (PAG) and a in similar oil, dubbed as