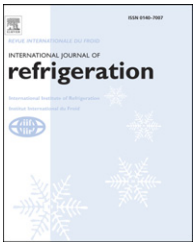
available at www.sciencedirect.com
journal homepage: www.elsevier.com/locate/ijrefrig



Prediction of refrigerant absorption and onset of natural convection in lubricant oil

Jader R. Barbosa[a,*], *Stefan M. Thoma*[b], *Moisés A. Marcelino Neto*[a]

[a]*Department of Mechanical Engineering, Federal University of Santa Catarina, Florianópolis, SC 88040900, Brazil*
[b]*Department of Mechanical and Process Engineering, Swiss Federal Institute of Technology, Sonneggstrasse 3, 8092 Zurich, Switzerland*

ARTICLE INFO

Article history:
Received 4 October 2007
Received in revised form
28 January 2008
Accepted 9 February 2008

Keywords:
Refrigeration system
Compression system
Survey
Absorption
Oil
Refrigerant
R134a
Modelling
Experiment

ABSTRACT

Refrigerant absorption and mixing in lubricant oil are important in the design of refrigeration compressors and refrigeration systems. Experimental work is reported on absorption of R-134a vapour through the top interface of an initially stagnant layer of pure lubricant oil. Since the liquid refrigerant is heavier than the oil, mixing is enhanced due to natural mass convection. In the present paper, the behaviour of the liquid temperature during absorption is described based on measurements carried out in a test rig consisting of a transparent 70 mm ID, 150 mm long, vertical glass tube through which absorption can be directly observed. Transient liquid temperatures were measured at three different heights in the test section (two in the vapour, one in the liquid). The experimental work is complemented by a theoretical analysis of the critical time for the onset of mass transfer induced Rayleigh instability. The model is based on a critical mass transfer Rayleigh number criterion widely reported in the literature and takes into account the variation of physical properties in the liquid layer. The critical time for the onset of natural mass convection increases with decreasing system pressure as a result of a lower equilibrium concentration at the vapour–liquid interface.

Prévision de l'absorption du frigorigène et du démarrage de la convection naturelle dans de l'huile lubrifiante

Mots clés : Système frigorifique ; Système à compression ; Enquête ; Absorption ; Huile ; Frigorigène ; R134a ; Modélisation ; Expérimentation

1. Introduction

Choosing the correct working fluids for a particular refrigeration application is crucial for an efficient and reliable operation of the system and of its components. In hermetic reciprocating refrigeration compressors, the thermophysical properties of the lubricant are strongly affected by the intense mixing between oil and refrigerant. For instance, because of

---

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

doi:10.1016/j.ijrefrig.2008.02.001

Nomenclature

A	cross-section area of test section (m^2)
C	constant in Eq. (5)
g	acceleration due to gravity (m/s^2)
He	Henry constant (J/kmol)
He^*	Henry number (–)
L	depth of liquid layer (m)
L_T	height of test section (m)
M_{in}	initial mass of refrigerant in the vapour phase (kg)
m''_I	interfacial mass flux ($kg/m^2\,s$)
n	constant in Eq. (5) (–)
p	pressure (Pa)
R	gas constant (J/kg K)
Ra	Rayleigh number (–)
Ra^*	Rayleigh number based on density gradient (–)
Sh	Sherwood number (–)
t	time (s)
T	temperature (°C, K)
x	local refrigerant mass fraction (kg/kg)
x_I	interfacial refrigerant mass fraction (kg/kg)
$\bar{x}_R$	volume averaged refrigerant liquid mass fraction (kg/kg)
$\tilde{x}_R$	volume averaged refrigerant liquid molar fraction (kmol/kmol)
z	downward distance measured from the liquid–vapour interface (m)
z_{max}	z at which maximum Ra^* takes place (m)
z_P	penetration depth (m)
Greek	
β	mass transfer coefficient ($kg/m^2\,s$)
δ	mass diffusivity (m^2/s)
η	dynamic viscosity (Pa s)
ρ	mass density (kg/m^3)
Subscripts	
G	vapour
L	liquid
O	oil
R	refrigerant
Superscripts	
∼	molar property
–	volume average property

the large difference between the viscosity of the pure oil and that of the liquid refrigerant, even small amounts of refrigerant dissolved in the oil may hamper compressor lubrication and hence reduce its life span. 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 (e.g., refrigerators and freezers), refrigeration capacity control is achieved via a succession of on-off compressor. During each cycle, immediately after the compressor turns off, a process of absorption of the refrigerant vapour in the oil inside the compressor shell is initiated. In reciprocating compressors, low equalizing pressures (that depend on thermodynamic and heat and mass transport aspects of the oil and refrigerant mixture) are often pursued as they mean reduced torque and less power required for compressor start-up.

Refrigerant absorption in lubricant oil has been investigated by many authors in recent years (Fukuta et al., 1995; Goswami et al., 1998; Yokozeki, 2002; Gessner and Barbosa, 2006). Silva (2004) conducted a series of experiments to determine the rates of absorption of R-12 in mineral oil and of R-134 in polyol ester (POE) oil. Silva (2004) measured the rates of pressure decay due to refrigerant absorption in a closed system. Experiments were performed at 15, 20 and 23 °C and the initial pressure of the refrigerant was of the order of 300 kPa in all cases. A 2D transient model based on mass, momentum and species conservation equations for the liquid mixture was proposed and the time-dependent refrigerant absorption was calculated taking into account the variation of the height of the liquid layer. Fukuta et al. (2005) conducted a visualization study of R-600a absorption and desorption in oil. They measured the corresponding mass transfer rates and correlated them for conditions in which the system pressure was kept constant. Barbosa and Ortolan (2008) evaluated experimentally and theoretically the absorption of R-134a and R-600a in initially pure polyol ester lubricant oils at room temperature for a number of conditions in which the system pressure varied as a result of refrigerant absorption. The liquid–vapour interface temperature was measured as a function of time in some experimental runs. The temperature increase as a function of time during refrigerant absorption (latent heat release) was observed.

The primary objective of this paper is to present a methodology for calculating the critical time associated with the onset of absorption induced mass convection in refrigerant–oil systems. Depending on the refrigerant–oil pair, the liquid refrigerant is heavier than the oil and mixing is enhanced due to natural mass convection. This Rayleigh-unstable behaviour is typical of HFC refrigerants, such as R-134a. In contrast, in systems where the liquid refrigerant is less dense than the oil (for example, R-600a and R-290) liquid density instability near the interface does not occur and absorption takes place by molecular diffusion alone. In unstable systems, convection is initiated by transient mass diffusion in a thin layer of liquid below the surface. The presence of an adverse density gradient near the surface (which may result from a combination of gravity and surface tension effects) gives rise to a dense layer that, once a stability limit is exceeded, plunges down as sheets and columns that evolve into inverted expanding plumes as they descend into the bulk liquid (Tan and Thorpe, 1996). The model presented here is based on the transient mass transfer Rayleigh number criterion of Tan and Thorpe (1999a) and takes into account the variation of physical properties in the liquid layer. As will be shown, the critical time for the onset of convection decreases with the system pressure as a result of higher equilibrium