

Absorption and Foaming Dynamics of Refrigerant R134a in Polyolester Oil

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Abstract: *The study of the absorption and foaming processes of a mixture composed by oil and refrigerant is of fundamental importance for the good compressor operation. This paper presents experimental data for the transient absorption process of refrigerant R134a in Polyolester Oil. The saturation concentration of the refrigerant in the oil, denominated solubility, are also determined for the operation condition and the behaviour of the liquid temperature during the outgassing is described based on measurements along time. The obtained results agreed well with the few available data in the literature. In addition, due to the liquid refrigerant is heavier than the oil, the mixing is enhanced due to the natural mass convection. The visualization of the transient absorption phenomenon was also performed to analyze qualitatively the mass natural convection.*

Keywords: *Solubility, Absorption, Mass Natural Convection, Oil, Refrigerant*

1. INTRODUCTION

In vapor compression refrigeration systems two fluids always interact with each other along the cycle: the refrigerant, that is the responsible for the heat transfer in the evaporator and condenser, and the lubricant oil, whose main function is to reduce the friction among the moving parts of the compressor. In addition, the lubricant oil helps to remove heat, inhibits the corrosion, reduces the noise and acts as a sealing fluid, reducing the refrigerant leakage, which increases the volumetric efficiency of the compressor. For all these reasons, the lubricant oil is important to provide a good compressor operation and, consequently, to assure a large useful life.

The presence of two fluids in the same cycle causes the interaction between them. Their mutual solubility changes the physical properties of the resulting fluid (the oil-refrigerant mixture) and, consequently, the operation of all the components, especially the compressor. The lubricant oil viscosity usually decreases with the presence of dissolved refrigerant, which can damage the lubrication system. In addition, the presence of refrigerant in the oil strongly influences the refrigerant leakage through several gaps of the compressor (Gasche, 1996).

However, the refrigerant solubility in the oil has the advantage of assisting oil circulation in the system, favoring its return to the compressor. A good circulation of the oil reduces its accumulation in evaporator and condensers, improving the heat transfer efficiency and reducing the refrigerant pressure loss.

Several researchers have determined the solubility of refrigerant in oil: Silva (2004), Barbosa et al. (2007), Fukuta et al. (2005), Marcelino Neto (2006) and Yokozeki et al. (2002). However, there are few data of polyolester-refrigerant R134a mixture solubility in literature. In addition, the unsteady behaviour of the absorption and outgassing phenomena for this type mixture is still rare to find out.

In the present work, the unsteady characteristics of the absorption and outgassing processes of the refrigerant R134a in polyolester oil are experimentally investigated. The transient absorption process is studied by measuring the height of the liquid mixture along the time until the steady state is reached. The outgassing process is investigated by using the methodology proposed by Goswami et al. (1998) and Heide (2001).

2. METHODOLOGY

Two types of test were performed using the same experimental facility: transient absorption tests and transient outgassing tests.

2.1 Transient Absorption Test

The experimental facility is schematically illustrated in Fig. 1. Initially, a specified amount of lubricant oil is loaded in the equilibrium cell. The cell is a borosilicate glass tube with an internal diameter of 40 mm and height of 300 mm, assembled between two circular aluminum plates, where a thermocouple and a transducer pressure are installed. Silicon rubber gaskets seal the contact between the plates and the glass tube. Vacuum is generated in the cell to remove air and the moisture and dissolved gases in the oil. The cell test containing oil under vacuum is weighed. By subtracting that mass from the empty cell mass, also under vacuum, one can determine the pure oil mass contained in the equilibrium cell, which is necessary for future calculations.

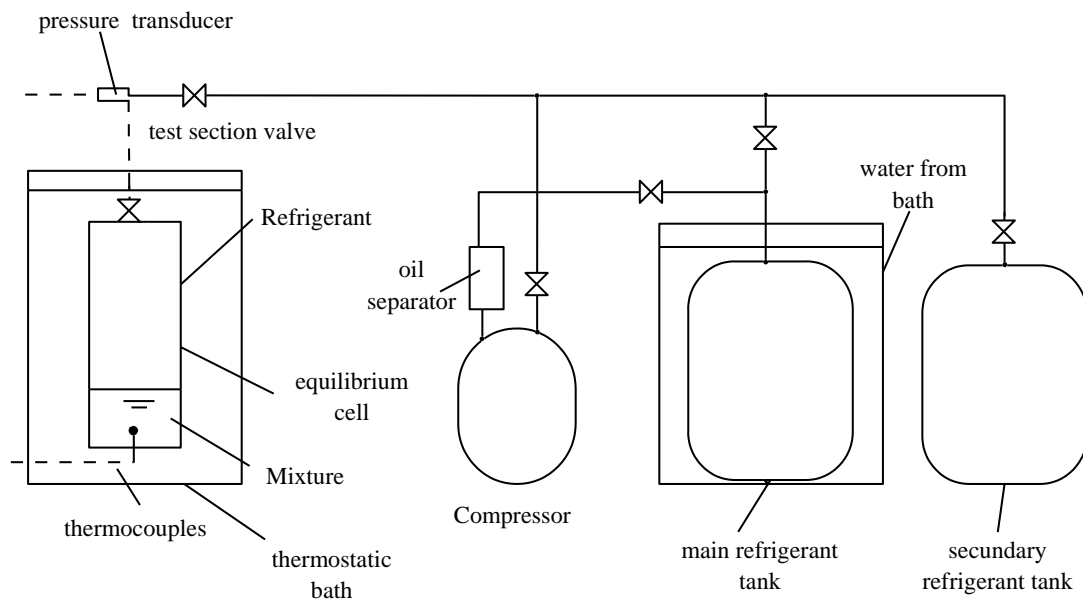


Figure 1. Schematic representation of the experimental apparatus

For accomplishing the oil saturation test, the pressure inside the glass tube is maintained constant. The cell test is connected to the main refrigerant tank containing saturated liquid refrigerant. The pressure inside the main refrigerant tank is maintained constant by controlling the saturation temperature through the use of a thermostatic bath and an auxiliary water reservoir made from acrylic. Other thermostatic bath and water reservoir are used to control the equilibrium cell temperature. The used for studying the unsteady saturation of the oil consists of measuring the liquid mixture height inside the glass tube along time, until the thermodynamic equilibrium is reached.

Once the thermodynamic equilibrium is reached, the cell test is removed from the acrylic reservoir and the mass is measured. The mass of the oil-refrigerant mixture is calculated subtracting from the total mass, the mass of the cell test. By knowing the initial oil mass of the oil inside of the cell test and using the ideal mixture model (additive volumes) it is possible to determine the solubility of the refrigerant in the oil for the pressure and temperature conditions set in the test.

2.2 Outgassing Test

The outgassing test is performed just after a saturation test by opening the test section valve, which allows the refrigerant to flow to the secondary refrigerant tank initially in vacuum. The abrupt reduction of the pressure inside the cell test, depending on the solubility, temperature and pressure conditions, can produce the foaming of the mixture. Temperature and pressure are measured along time using a data acquisition system.

3. CALCULATION OF THE REFRIGERANT CONCENTRATION IN THE OIL

Using the height of the liquid, one can determine the instantaneous concentration of the refrigerant in the oil if the ideal solution is used for modeling the mixture behavior. The same procedure can be used to calculate the mixture solubility.

Figure 2 illustrates the cell test before (a) and after (b) the saturation of the mixture is reached. Initially, pure oil is contained in the cell test. After the thermodynamic equilibrium, the liquid phase of the mixture is constituted by oil and refrigerant. Pure refrigerant vapor is supposed to fill the rest of the cell test.

The instantaneous total mass of the cell test, m_t , is given by:

$$m_t = m_o + m_{SV} + m_{RL} + m_{RV} \quad (1)$$

where m_o is the initial oil mass, m_{SV} is the mass of the empty cell test, m_{RL} is the mass of the liquid refrigerant in the mixture, and m_{RV} is the refrigerant mass in the vapor phase.

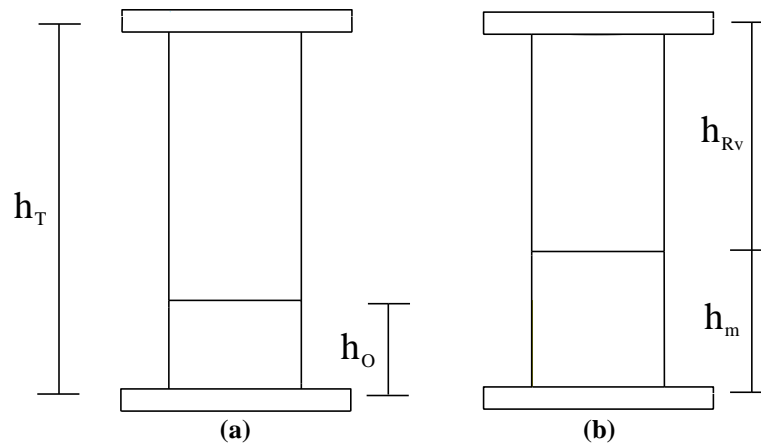


Figure 2. Cell test (a) containing pure oil and (b) after the thermodynamic equilibrium is reached.

Assuming that the vapor phase is at the same pressure and temperature of the liquid mixture, the mass of the refrigerant vapor can be calculated by:

$$m_{RV} = \frac{V}{v(T,p)} \quad (2)$$

where V is volume occupied by the vapor phase and $v(T,p)$ is the specific volume of the refrigerant calculated at (T, p) of the mixture.

The volume, V , can be determined by measuring the height of the vapor phase, h_{RV} , by the following equation:

$$V = A_{st} \cdot h_{RV} = \frac{\pi \cdot D^2 \cdot h_{RV}}{4} \quad (3)$$

Therefore, using Eqs. (1), (2) and (3) one can calculate the mass of the refrigerant dissolved in the mixture by:

$$m_{RL} = m_t - m_o - m_{SV} - \left(\frac{\pi \cdot D^2 \cdot h_{RV}}{4 \cdot v(T,p)} \right) \quad (4)$$

The instantaneous refrigerant concentration in the oil, in percentage, is defined by:

$$w(\%) = \left(\frac{m_{RL}}{m_o + m_{RL}} \right) \cdot 100 \quad (5)$$

or using Eq. (4),

$$w(\%) = \left(\frac{m_t - m_o - m_{SV} - \frac{\pi \cdot D^2 \cdot h_{RV}}{4 \cdot v(T,p)}}{m_t - m_{SV} - \frac{\pi \cdot D^2 \cdot h_{RV}}{4 \cdot v(T,p)}} \right) \cdot 100 \quad (6)$$

All the variables in the right side of the Eq. (6) are known, which allows the calculation of the instantaneous refrigerant concentration and, consequently, the solubility of the refrigerant in the oil for the pressure and temperature set in the test.

4. RESULTS

First of all, it is presented visualization results for the unsteady process of refrigerant absorption in the oil. Figure 3 shows some pictures of this process for $T=38.6$ °C and $p=5.3$ bar.

The absorption process of refrigerant starts with the refrigerant diffusion at the liquid-vapor interface. The absorption of refrigerant in the oil changes the mixture index refraction, which allows the visualization of the process. As the refrigerant density is larger than the oil density, a combined effect of natural convection occurs after the initial diffusion process at the interface.

The same type of pictures is used to measure the height of the liquid mixture that is used to calculate the instantaneous refrigerant concentration and the final equilibrium concentration, that is, the oil-refrigerant solubility.

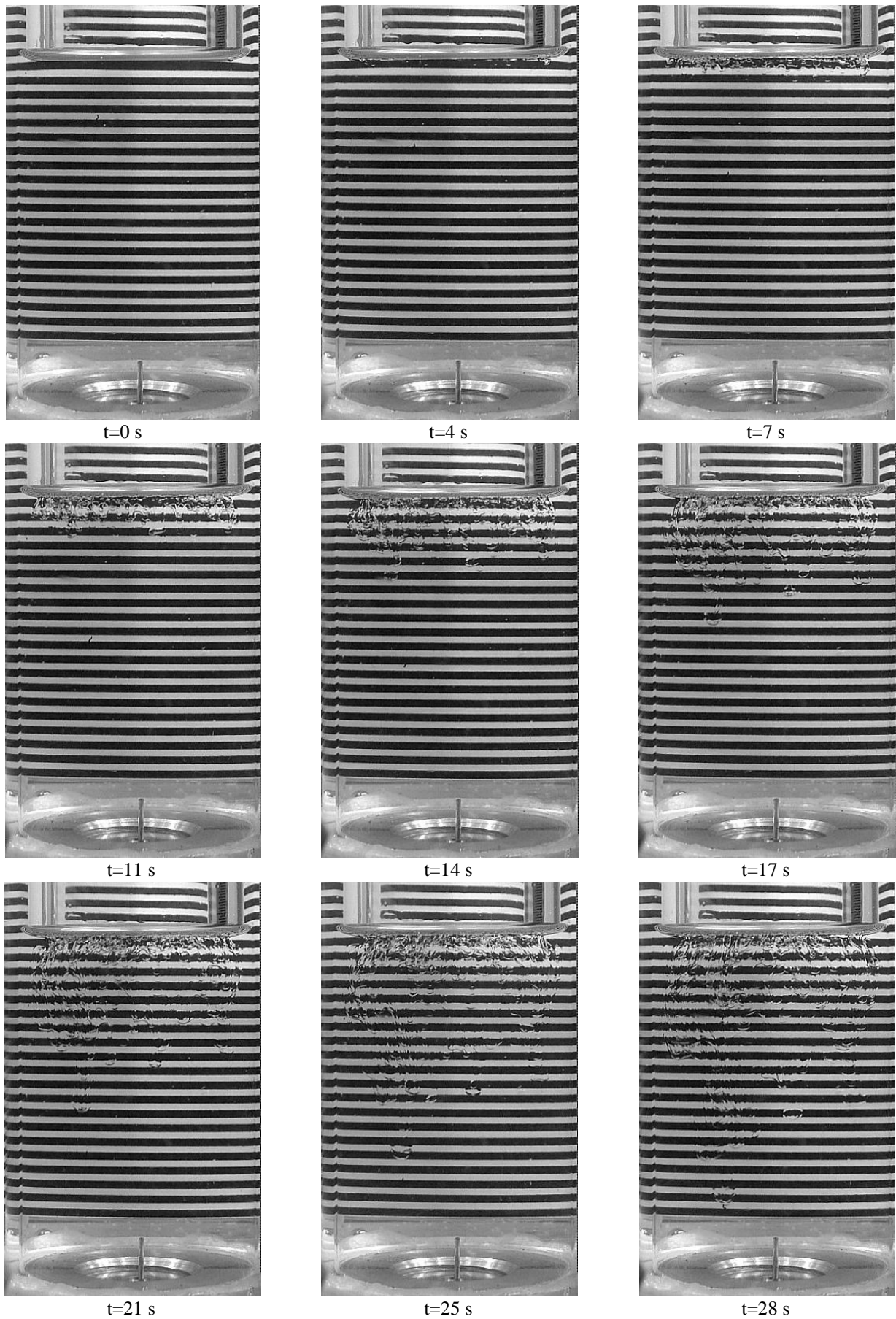


Figure 3. Visualization of R-134a absorption in polyolester oil.

Figure 4 shows the unsteady absorption process through the measure of the instantaneous height of the liquid mixture until the saturation is reached for $T=38.8^{\circ}\text{C}$ and $p=5.36$ bar. Figure 5 depicts similar results for $T=38.7^{\circ}\text{C}$ and $p=4.03$ bar. These pictures show a good repeatability of the tests. As expected, the unsteady absorption process is very slow. It is necessary about 10 hours in order to reach the equilibrium condition.

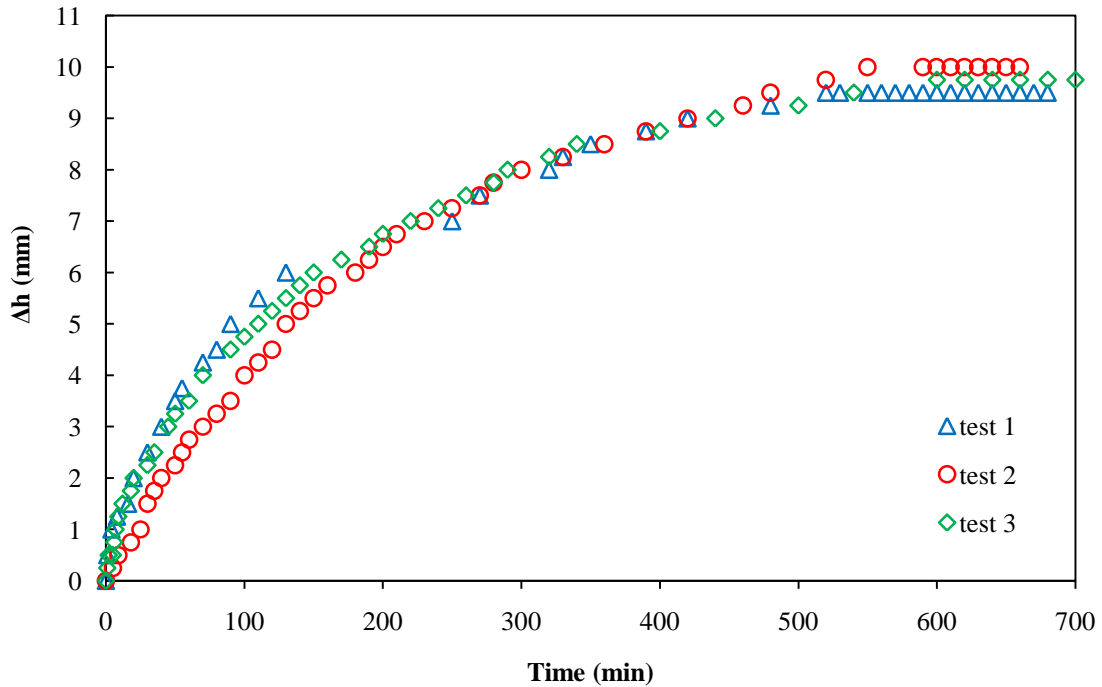


Figure 4. Variation of the mixture height for $T=38.8^{\circ}\text{C}$ and $p=5.36$ bar

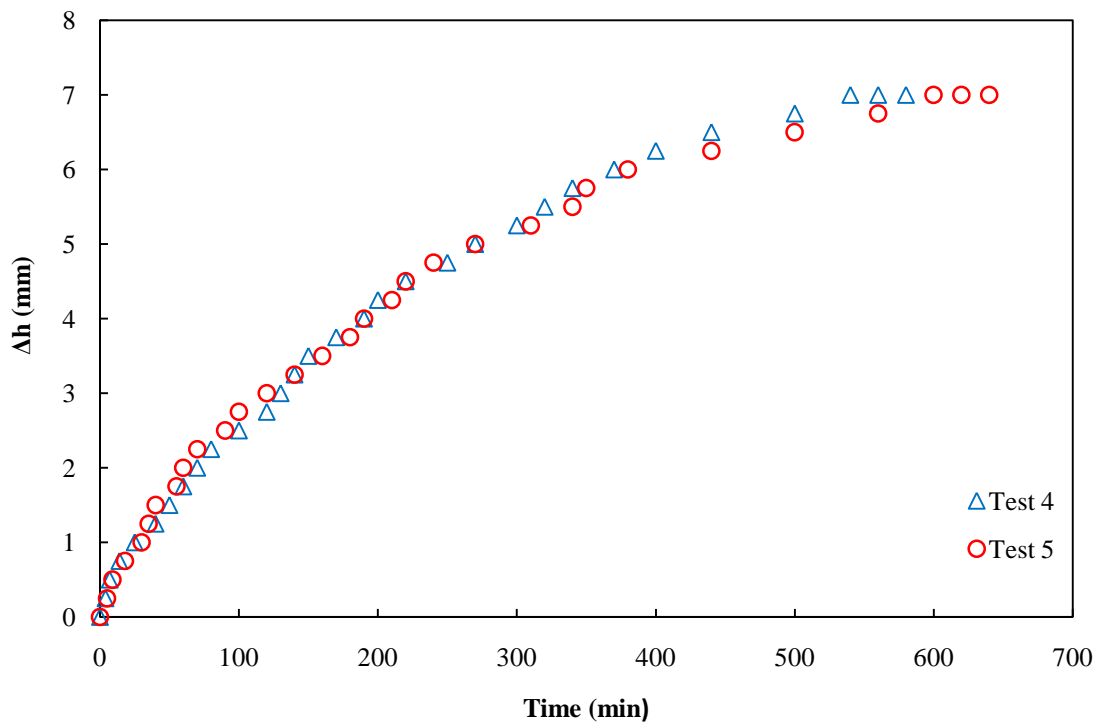


Figure 5. Variation of the mixture height for $T=38.7^{\circ}\text{C}$ and $p=4.03$ bar

Using the data at the equilibrium condition, it is possible to calculate the solubility of the refrigerant in the oil for all tests. Figures 6 and 7 show these results when compared with the solubility data obtained by Monte Verde and Gasche (2008) through the Eq. (7), which has been fitted using the data from Castro (2006).

$$w(\%) = \left(\frac{a_1 + b_1 \cdot P + c_1 \cdot T + d_1 \cdot P^2 + e_1 \cdot T^2}{a_2 + b_2 \cdot P + c_2 \cdot T + d_2 \cdot P^2 + e_2 \cdot T^2} \right) \cdot 100 \quad (7)$$

where: $a_1 = 837.98306$, $a_2 = 93.310491$, $b_1 = -296.37837$, $b_2 = -63.334877$, $c_1 = 14.305198$, $c_2 = -1.3351068$, $d_1 = 429.70749$, $d_2 = 6.866082$, $e_1 = 1.329373$, $e_2 = 0.46517071$, T is the temperature in °C and p is the absolute pressure in bar. The fitted curve has been validated for $0 < p < 11$ bar and $0 < T < 60$ °C.

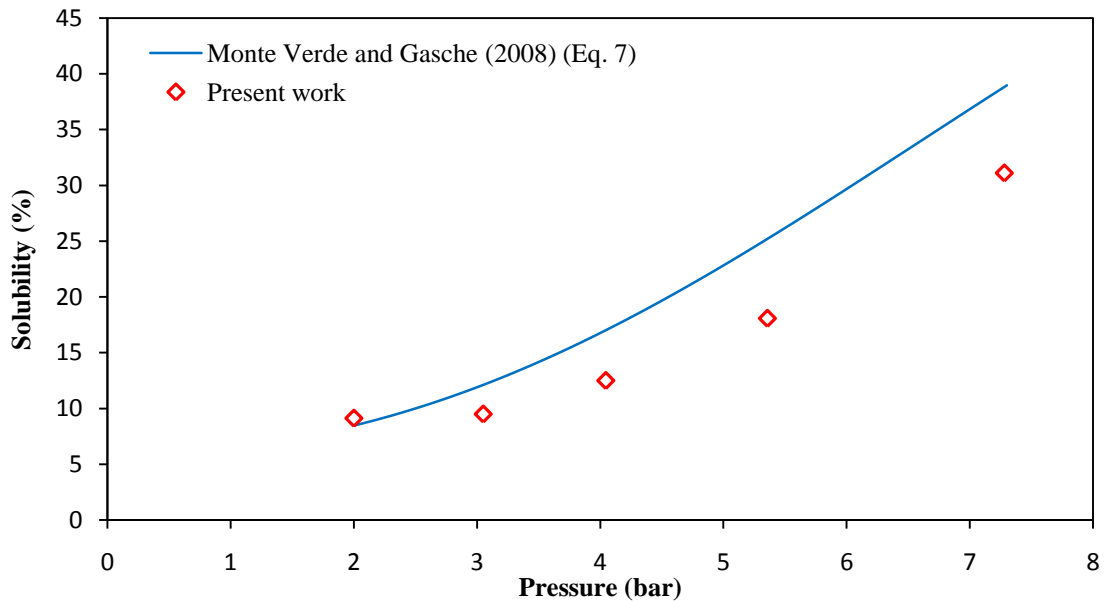


Figure 6. Solubility data for T=38.7 °C.

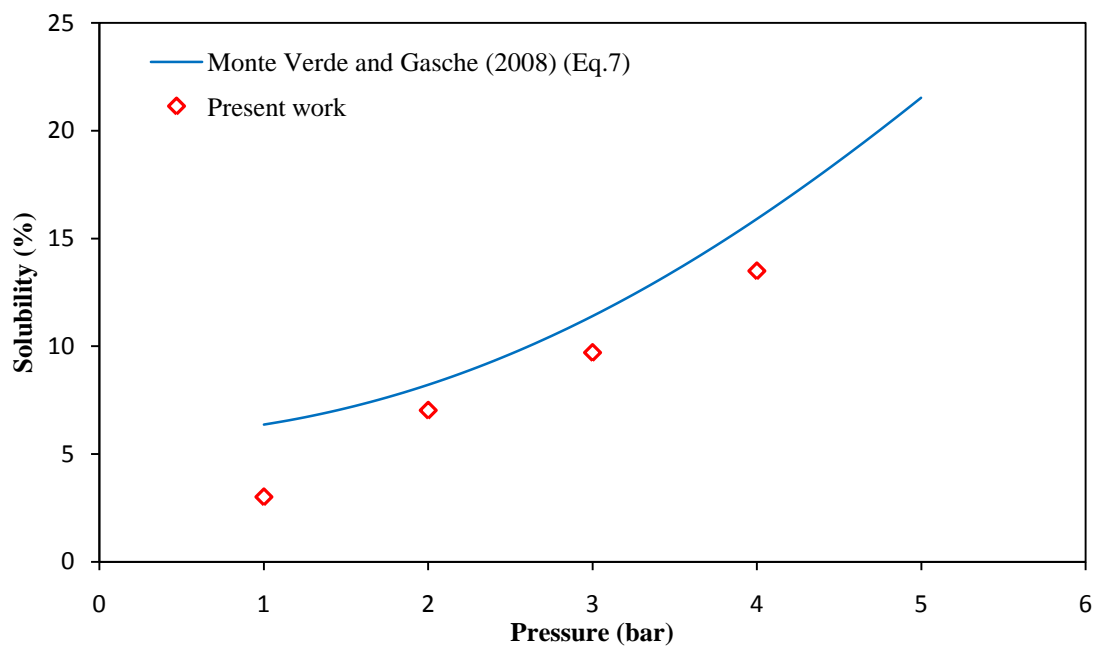


Figure 7. Solubility data for T=40 °C.

As can be noticed in Figs. 6 and 7, the discrepancies among the results are large. All experimental results, except one for $p=2$ bar and $T=38.7$ °C, are lower than those predicted by Eq. (7). However, neglecting the first point in Fig. 6,

the experimental data seems to be more physically coherent. It is noticed that the fitted curve, Eq. (7), tends to provide non-zero solubility as the pressure tends to zero. The experimental results present this tendency. In order to corroborate these results, a greater number of the tests is necessary, including other operations conditions.

The outgassing tests were performed just after the saturation tests in order to analyze the temperature drop for a given pressure drop. Figure 8 presents the unsteady behavior of the pressure and the temperature for a saturation test performed at $p=3$ bar and $T=41^\circ\text{C}$. It is observed a 1.5°C temperature drop for a 3 bar pressure drop. This temperature drop is caused by the liquid to vapor phase change of the refrigerant in the mixture.

Depending on the operational condition this liquid-vapor phase change can produce foam formation in the mixture.

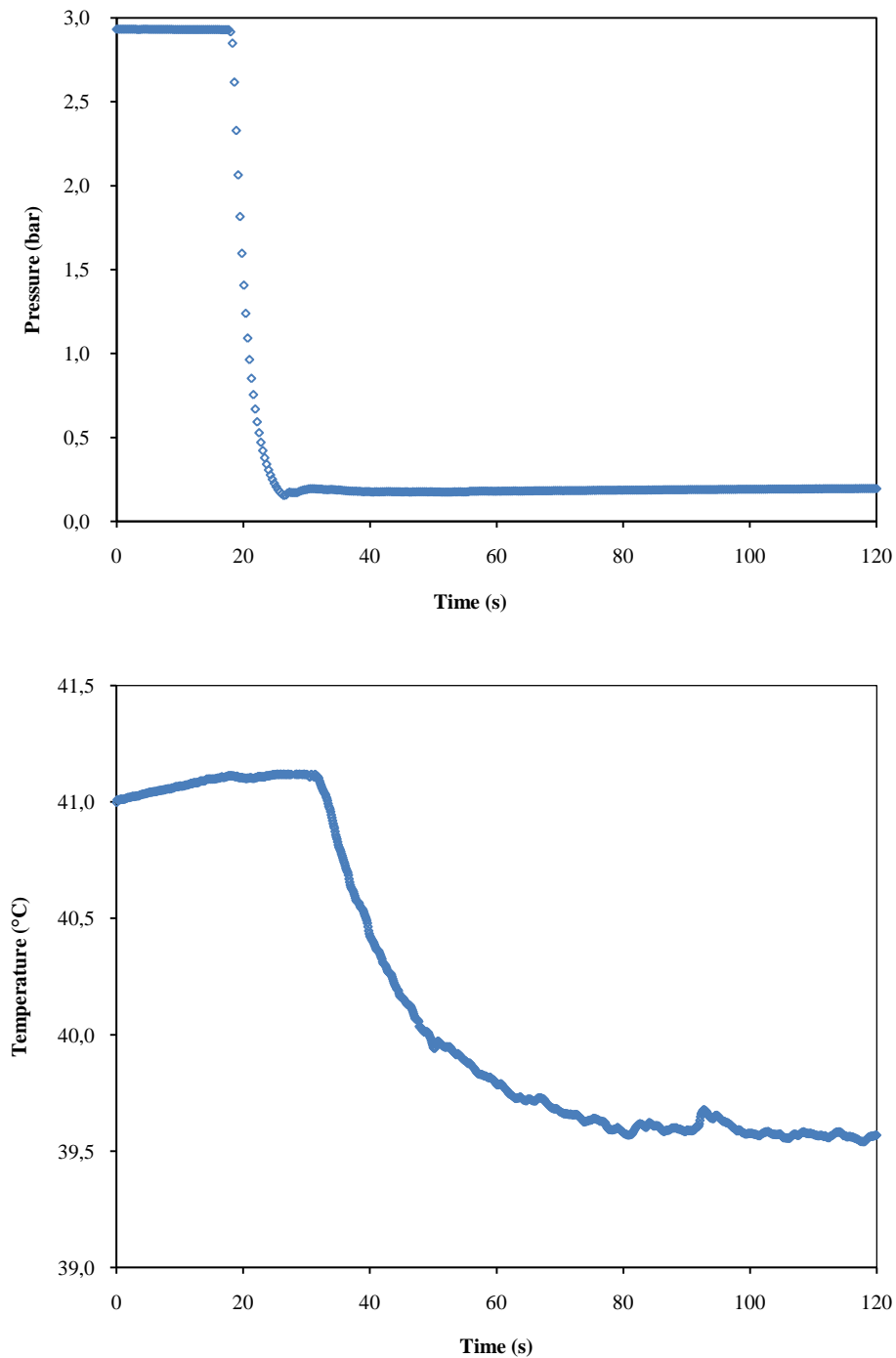


Figure 8. Unsteady behavior of temperature and pressure for at $T=41^\circ\text{C}$ and $p=3\text{bar}$.

Table 1 presents other temperature drop data for different operational conditions. Except for the test performed at $T=38.5^{\circ}\text{C}$ and $p=3.5$ bar, it is observed that the temperature drop increases for increasing solubility. This is physically coherent because the large the solubility the larger the amount of refrigerant that changes the phase, which reduces the mixture temperature.

Table1. Temperature Variation for different outgassing processes.

Operational Condition	Temperature Variation ($^{\circ}\text{C}$)	Solubility (%) (Eq. 7)
$T=41^{\circ}\text{C}$ $P=3$ bar	$T_{\max} = 41.6$ $T_{\min} = 39.5$ $\Delta T_{\max} = 2.1$	11.0
$T=38.5^{\circ}\text{C}$ $P=3$ bar	$T_{\max} = 38.6$ $T_{\min} = 35.4$ $\Delta T_{\max} = 3.2$	12.0
$T=38.3^{\circ}\text{C}$ $P=3.8$ bar	$T_{\max} = 38.3$ $T_{\min} = 34.9$ $\Delta T_{\max} = 3.4$	16.0
$T=35.7^{\circ}\text{C}$ $P=5.2$ bar	$T_{\max} = 35.9$ $T_{\min} = 32.1$ $\Delta T_{\max} = 3.9$	28.1

5. CONCLUSIONS

The unsteady absorption and outgassing process of refrigerant R134a in lubricant polyolester oil was experimentally investigated in this work. The solubility of the refrigerant in the lubricant was also experimentally predicted. An average deviation of approximately 24.5% in relation to the literature data, Eq. 7, was founded. However the tendency of the experimental results seems to be more physically coherent. The outgassing tests show that the temperature drop increases for increasing initial solubility for the most tests.

6. ACKNOWLEDGEMENTS

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