Experimental Study on Fractionation of R-407C and Recharge Operations

M. Paulus-Lanckriet
Solvay Research & Technology

O. Buyle
Solvay Research & Technology

EXPERIMENTAL STUDY ON FRACTIONATION OF R-407C AND RECHARGE OPERATIONS

M. Paulus-Lanckriet, O. Buyle
SOLVAY RESEARCH & TECHNOLOGY
Business Unit Fluorochemicals

ABSTRACT

This paper provides an update on our knowledge in the field of R-407C fractionation and evaluates its impact while the system is in operation. Furthermore, the impact of leakages has been evaluated in terms of performance changes and fractionation of R-407C. Concentration shifts also result from common practice in the servicing of refrigeration installations. All these potential problems with R-407C have been quantified in an existing experimental refrigeration system, including recharge operations. The paper gives a summary of our latest results on fractionation and recharge tests leading to practical recommendations for the use of R-407C.

INTRODUCTION

In the context of the R-22 phase-out starting in Europe in the year 2000, HFCs are developed as efficient substitutes in refrigeration and air conditioning systems. These refrigerants are already used in new equipments for applications where R-22 would have been chosen in the past. R-22 will not be replaced by only one single substitute, but by a range of products. Depending on the application, pure HFCs or mixtures of HFCs are taken into account. In particular, R-407C and R-410A are recognized worldwide as promising substitutes for R-22. R-407C (HFC-32/ HFC-125/HFC-134a 23/25/52 %) is a zeotropic mixture with a significant temperature glide (7 K).

Up to now, the use of zeotropic refrigerants was limited to special cases. If R-407C becomes widely used in usual R-22 applications, there is a need to investigate the practical implications arising from its zeotropic character.

The fractionation of R-407C has already been studied experimentally by the authors under typical refrigeration conditions and first data have been published **[1]**. The present paper provides an update on our knowledge in this field and evaluates the impact of the fractionation while the system is in operation.

STATE OF KNOWLEDGE ON FRACTIONATION – A QUICK OVERVIEW

Introduction

Several studies have already been published about the effect of the zeotropic character of mixtures, most of them based on leakage tests, with possibly recharge processes. Some of these publications are based on experimental determinations, others on computer simulations, but most of them give mainly the consequences on performance parameters (COP and volumetric capacity) in case of a leak. An overview has already been given by Chen., Kruse and Wischollek (**[2]**, **[3]**, **[4]**), which include in the last case the influence of fractionation and partial miscibility of components in oils.

Fractionation of R-407C in a Refrigeration Systems

Apart from the reference **[1]**, only two other publications are related to the fractionation of R-407C in the refrigeration installation without any leak. Goth **[5]**, with the simulation of an installation equipped with an important accumulator; estimates the circulating composition is enriched in HFC-134a (increase between 5 and 10 %in the circulating composition). Surprisingly, he finds that the phenomenon is opposite, with a decrease in the HFC-134a concentration, when the installation is not equipped with a liquid accumulator.

Corr and Murphy **[6]**, by simulation, give the same results as the previous one without accumulator, for the circulating composition. They found concentrations of HFC-32/ HFC-125/HFC-134a 25/27.3/47.7 %). They confirm **[1]** with the concentrations of the components in a vapor phase in contact with a liquid one : they are roughly equal to each other (≈ 33 weight%). However, the location of the determination is different (in the condenser for the work reported in **[6]**, instead of at the entrance of the evaporator for the work reported in **[1]**).

R-407C Fractionation during Leak Scenarios

It is quite difficult to compare the results between the different tests and calculations published in the literature. As recognized above, the results depend on the type of equipment. Also important are the operating conditions, temperatures in the heat exchangers and leak scenario, for example. The general criterion for the recharge of refrigerant is also different in each case : the apparition of first bubbles in the sight glass, or the supposition made that a critical lack of refrigerant is reached (in all the cases, between 90 % and 60 % of the initial R-407C charge). However, general tendencies can be drawn. The leak is generally in vapor phase, located after the expansion valve. Only Stanbouly **[7]** has investigated other locations, but it is evident that a leak in vapor phase after the expansion valve leads to the higher effects on R-407C compositions and performances. In reference **[7]**, no refrigerant analysis was performed, but both COP and cooling capacities decreased of a few percents after five leak/recharges.

The simulation of an evaporator vapor leak by Bresnahan and Low **[8]** gives quite optimistic results : only a few percent enrichment of HFC-134a in the leak when no liquid remains in the condenser, the system must then be recharged. The sole effect on performances is a decrease by a few percents of the refrigeration capacity of R-407C after a few leak/recharge cycles.

Tests in a supermarket cabinet described by Kruse and Chen **[9]** have also shown that after 8 % and 50 % of loss of charge, the circulating composition is quite different from the R-407C nominal composition, HFC-32/HFC-125/HFC-134a 21/24/55 % and 18/21/61 % respectively for a leak of 8 % and 50 %.

When only performances are estimated by calculations based on static leak tests in the vapor phase (Preisegger and Bivens, **[10] [11]**), the volumetric capacity is recognized to decrease by a few percents. An increase in COP is even noted in **[10]**.because of the higher HFC-134a content.

In order to complete our knowledge in that field, we have thus combined both GC analysis for the fractionation study and experimental performances determination of a specially designed refrigeration equipment. The results are described in the following part of the paper.

EXPERIMENTAL RECHARGE SCENARIOS

Introduction

The effect of successive leak and recharge processes has been investigated in an experimental system, fully equipped with measuring devices allowing the measurement of pressure, temperature and flow rate of the refrigerant at different points of the cycle. The equipment allows also the sampling of refrigerant in different locations, for further GC analysis.

Description of the Refrigeration Equipment

The experimental refrigeration installation (**Figure 1**) was designed for R-22 and used as such for R-407C. It is equipped with a semi-hermetic compressor. The refrigerant flow rate is measured with a Coriolis massflow meter. The condenser is water-cooled and the evaporator is a liquid/glycol dry heat exchanger. The inlet temperatures of water and glycol are maintained constant; the flow-rates are regulated by a three-way valve and the temperature is fixed with thermocryostats before the inlet in the heat exchangers. The flows are also measured with volumetric flowmeters.

Six locations have been taken for the sampling of the refrigerant : before and after the condenser, the receiver and the evaporator (see **figure 2**). Among all locations, only the sample at the entrance of the evaporator is a "two-phase" sample in the refrigeration device. The valve connection is realized on the upper side of the tubing, in such a way as to provide the vapor phase at this location. It is also used for the simulation of the leak at this point.

Each sample has been analyzed by gas chromatography, in order to show the possible segregation between HFC-32, HFC-125, and HFC-134a.

Experimental Conditions

The running conditions were -20 °C at the evaporator (bubble temperature) and 40 °C at the condenser (dew temperature), with a constant superheat of 2 K in the evaporator. As previously mentioned, the location of the leak has been chosen in order to provide the worst effect on the composition : in vapor phase at the entrance of the evaporator. The refrigerant was recovered in a bottle placed on a scale. The weight of each sample was close to 0.300 kg for an initial charge of 8 kg.

The composition of the refrigerant recovered from the installation, initially charged with R-407C, has been determined during each leak process before recharge. The latter sampling was made when a total of 1 kg refrigerant had leaked. This quantity corresponds to the apparition of the first bubbles in the sight glass, previously determined with an emptying simulation of the refrigeration equipment. Performances parameters were calculated at this stage, together with an analysis of the refrigerant in the bottle and of samples taken at the six location of the installation. This leak/recharge cycle was realized four times.

Results

Fractionation effect

The analysis of the leaked refrigerant was used to calculate the global composition of the refrigerant R-407C (initially HFC-32/HFC-125/HFC-134a 23/25/52 %) remaining in the refrigeration equipment. The variation is presented in **figure 3**.

Taking into account the ASHRAE specifications which fix the concentration of the mixtures with a tolerance of ± 2 % by weight, the HFC-134a concentration reaches nearly the boundary after the first leak and exceeds 54 % during the second leak. The level of 21 % for HFC-32 and 23 % for HFC-125 is reached during the third leak process. There is no significant effect by recharge of R-407C.

The concentrations at the different locations of the installation are presented in **table 1**, at the initial stage and after the four leak/recharge processes. They follow the same general trend as the global composition of the refrigerant as shown in **figure 3**.

Evolution of the Performances

The reduction in refrigeration capacity, electrical COP and volumetric capacity after the four leaking cycles are presented in **table 2**. They have been based on temperature, pressure and power measurements and taking into account the nominal R-407C thermodynamic properties or the thermodynamic properties of the real composition of the refrigerant remaining in the installation. This is done with REFPROP 5.0 from NIST.

The variations are hardly significant if the nominal composition of R-407C is taken for the calculations. However, a better estimation can be made with the real composition in which case a clear decrease is observed, respectively of 11 %, 4 %, and 8 % for the refrigeration capacity the electrical COP and the volumetric capacity. This is also in reasonable agreement with the literature discussed above.

CONCLUSION AND PRACTICAL IMPLICATIONS

Leak and recharge processes on a refrigeration installation with the zeotropic R-407C refrigerant show a quite important variation of the refrigerant composition in the equipment, leading to a refrigerant which can be significantly different from the nominal composition. The recharge with the nominal R-407C composition does not correct the shift of concentrations. It will thus be necessary to take care of this fact when R-407C must be recovered, reclaimed and/or recycled after use.

The effect of leak and recharge processes are in accordance with the previously published literature and show that the refrigeration capacity is the most affected parameter. It has to be noted that only four leaking processes have been realized, which is quite few in comparison with a real refrigeration equipment.

The reduction of the performance parameters is not revealed if they are calculated with the R-407C nominal composition. However, this decrease is quite real because of the change of composition due to the leak process, which is not corrected by a recharge with the R-407C nominal composition.

Even if it is quite difficult to evaluate the remaining composition in the equipment without any leak analysis, it would be necessary to adapt the recharge composition in order to recover the initial R-407C performances.

REFERENCES

[1] : M. Paulus-Lanckriet, O. Buyle, "R-407C/R-410A : an analysis of the two prominent candidates for the replacement of R-22 in refrigeration applications", IIF/IIR Conference Heat Pump Systems, Energy Efficiency, And Global Warming, Linz, Austria, 28.09/01.10.97

[2] : J. Chen, H. Kruse, "Kältemittelgemische als Substitute für R22, R502 und R13B1", AIF Forschungsvorhaben Nr 9841, Forschungsrat Kältetechnik, Frankfurt 1995

[3] : H. Kruse, F. Wischollek; E. Wobst; G. Ahnefeld, U. Hesse, "Konzentrationsverschiebung in Kreisprozessen bei Verwendung von Kältemittelgemischen", Forschungsrat Kältetechnik, Frankfurt 1996

[4] : F. Wischollek; H. Kruse, "Erprobung von Kältemittelgemischen im Verdichterkreislauf, Teilforschungsvorhaben A: Eigenschaften vonausgewählten Öl/Kältemittelgemischen", Forschungsrat Kältetechnik Frankfurt 1998

[5] : Y. Goth, "Ecart entre les compositions de charge et circulation dans une installation frigorifique", Journée "Fluide Frigorigènes de demain", Paris, France, 07.02.97

[6] : Stuart Corr, F. Thomas Murphy, Stuart Wilkinson, "Composition shifts of zeotropic HFC refrigerants in service", ASHRAE Transactions, US 1994, V.100, n°2, pp. 538-548

[7] : Stanbouly, "Serviceability issues associated with R-407C refrigerant", 1996 International Conference at Purdue University, July 1996

[8] : J.D. Bresnahan, R.E. Low, "Zeotropic refrigerants in the real world : performance testing of R22 and R502 alternatives based on R32/R125/R134a", 1995 AIRAH Conference, Melbourne

[9] : H. Kruse, J. Chen, "Cycle performance of alternative refrigerant mixtures", International seminar of Heat Transfer and Thermophysical Properties, Japan, 1993

[10] :E. Preisegger, "Aspects concerning the composition shifts in refrigerant blends", Fifth European Seminar for the Future of Refrigeration and Air Conditioning, Italy, 1995
[11] :D.A. Bivens and al.,"HCFC-22 alternative for air conditioners and heat pumps", ASHRAE Transactions, V. 100 n°2, 1994

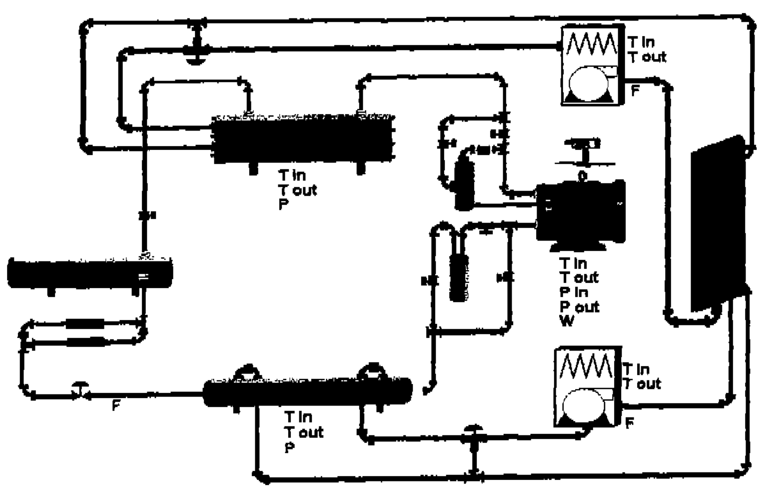

Figure 1 : Experimental refrigeration device

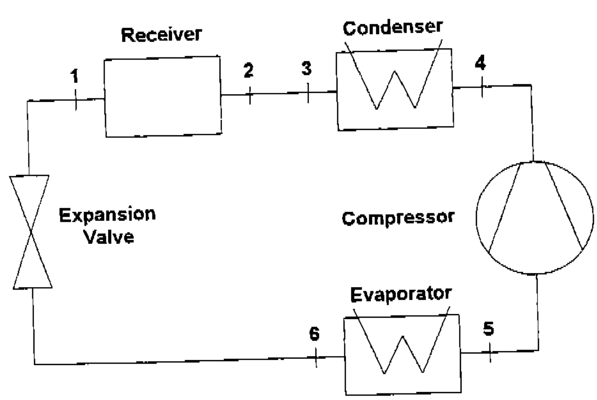

Figure 2 : Localization of the sampling points for the refrigerant fractionation determination

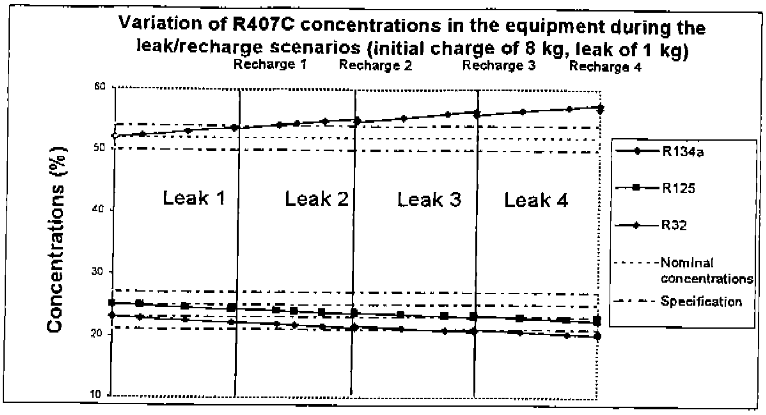

Figure 3 : Variation of the refrigerant composition during the four cycles

Location	HFC-32/HFC-125/HFC-134a Weight %	
	Initial	After four leak/recharge steps
Receiver inlet	23.2/25.5/51.3	20.1/22.6/57.3
Receiver outlet	22.9/25.3/51.8	20.0/22.6/57.4
Evaporator inlet	29.7/30.8/39.5	26.8/28.4/44.8
Evaporator outlet	22.1/24.9/53.0	19.9/22.5/57.6
Condenser inlet	25.0/26.6/48.4	21.6/23.6/54.9
Condenser outlet	24.2/26.1/49.7	21.4/23.5/55.0

Table 1 : Initial and final concentrations at the different locations of the refrigeration device

Parameter	Reduction, % calculated with R407C concentrations	Reduction, % calculated with real concentrations
Refrigeration capacity	2.7	11.0
Electrical COP	1.0	3.9
Volumetric capacity	3.0	8.0

Table 2 : Reduction of initial performances after the fourth recharge