MEASUREMENT AND CONTROL OF REFRIGERANT LEAKS

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1. European regulation and halogenated refrigerants

The 3093/94 European regulation indicates simply that all efforts contributing to the containment of refrigerants shall be implemented. This general recommendation applies only to CFC and HCFC included in this regulation. But due to the Kyoto Protocol this recommendation is more than welcome for new HFC refrigerants.

Actions aiming at the limitation of greenhouse gas emissions are being defined in European countries and different national policies are being published. Some European countries (The Netherlands, France, …) mention that leak-tightness inspections are a key point and make mandatory annual leak tightness inspections for installations charged with refrigerants except for domestic appliances. The implementation of regulation on leak tightness inspections requires the elaboration of standards for the performances of refrigerant leak detectors and room controllers.

In France, AFNOR (French Association for standards) took the initiative. A group of experts and industry representatives was set, and the standard E 35-422 on performances of leak detectors and room controllers was published in December 1999. This standard is proposed to the CEN to become a European standard.

This paper presents also first results of HFC leak detector performances commercially available in Europe. First the use of refrigerant leak detectors on site is reminded.

1. Methods of leak tightness inspection for contractors

Usual but also non-usual methods for leak tightness inspections are described briefly here below.

Sniffing method
This is a usual method. It consists in moving the leak detector nose as close as possible to the leak location. Most of user manuals do not indicate either the distance or the moving speed whereas these two parameters shall be mentioned to define the leak detector performance. For acceptable accuracy, the leak detector nose should not be farther than 2 mm of the leak location and the moving speed shall be in the range of 2 to 5 mm/s, which is very slow. It is necessary to emphasize that the effectiveness of leak tightness inspection requires to define moving speed and distance.

When several potential leak locations shall be inspected by the sniffing method, the operation needs to be organized. The contractor has preferably a list of marked out components and proceed systematically line by line: discharge, liquid suction and by heat exchanger, in particular for outdoor condensers.

The envelopment method
The envelopment method, little or not used in refrigerating applications, is already very usual in the leak tightness inspection of volatile organic compounds, in particular in the United States. This method is also used in Europe in helium non-destructive methods.

The component to be checked, valve, fitting, Schrader valve, is enveloped in a vinyl sheet (see figure 1) closed by adhesive tape.

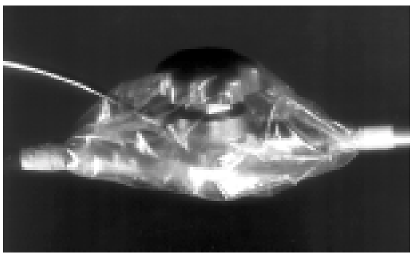

Figure 1: Example of a valve wrapped in a vinyl sheet

The envelopment shall be tight but no pressure difference exists. Precautions remain reasonable. The system is under refrigerant pressure. About ten hours after components have been enveloped, each of them is pierced with an ad-hoc leak detector. Then the concentration is measured. As long as the concentration is lower than the defined leak tightness threshold, the detector nose needs not to be moved again. This method may appear cumbersome but is adapted mainly to factory leak tightness qualification. It could be useful to compare the ratio time/leak tightness accuracy to determine the best-suited method for leak tightness inspection during maintenance: either sniffing or envelopment.

Associated Methods

Soap Bubble Method
Contractors use frequently, and with good reason, the soap bubble method where the system is under nitrogen pressure. This method is fast and visual. Its efficiency depends on the internal pressure. The accuracy can reach between 10 and 30 g/yr., but the sensitivity is lower than those of good sniffing leak detectors. The method is particularly useful for the verification of brazing leak tightness before refrigerant charge.

Leak detection with fluorescent products
Some fluorescent products are available and can be blended with the compressor oil. When circulating in the circuit, the fluorescent oil makes leak detection visual and easy. This idea came up from a well-established observation, significant refrigerant leaks are noticed because of oil drops either on the ground or on the pipe. This old observation by contractors is now implemented by the use of ultraviolet lamps that permit to see slight oil spots.

Similarly to the bubble soap method, the sensitivity of this method is depending on the internal pressure. Because of its high viscosity when oil starts to diffuse through the leak, it means that the leak site is already significant. The definition of a repeatable sensitivity threshold of such a device is impossible. This easy and quick method can only be performed in addition to leak detector inspections.

Room controllers
Significant progresses have been realized for room controllers in the past five years, in particular with the marketing of infrared spectrophotometers. This equipment can be multi sensors and include alarm and pre alarm thresholds. Their sensitivity is in the range of 1 to 50 ppmv. Because room controllers permit leak detection based on triggering alarms, they can be integrated advantageously in conditional maintenance methods. At the moment little experience based on lessons learnt exist, but it appears most possible that triggering alarm prevents from leak tightness rupture, when significant increase in refrigerant concentration occurs in machinery room.

Checklists
Leak tightness inspection results shall be registered for each component on an exhaustive list of system components. Progressively the list of the most leak prone components will be established and close watch of these components will imply changes aiming at their removal, or improvement, or continuous supervision.

The implementation of checklists yields to an initial lengthy descriptive work, but in the future these documents constitute an efficient structure both for systematic leak tightness inspections and for attentive control of leak prone components.

Systematic leak tightness inspection of refrigerating systems supposes:

- defined performances of leak detectors, and
- calibration by calibrated leaks.

2. Characteristics of portable leak detectors

For all measurement devices, it is necessary first to answer the questions: what is to be quantified? What is the minimum sensitivity range? For leak detectors, additional questions are: is the leak detector selective? What is the recovery time after detection of high refrigerant concentrations? Lastly, a portable leak detector shall be tested both in a fixed position and in motion.

What does a portable leak detector measure?
A leak detector measures gas concentration, in this case HFC refrigerant concentration existing in a defined volume. For portable leak detector, the detection volume also called control volume, is not known because it is depending on the distance between the detector nose and the leak site, and on the time spent in front of the leak site.

To be able to know what a leak detector measures, the standard shall define the distance between the leak site and detector nose, and the moving speed for a defined leak flow rate.

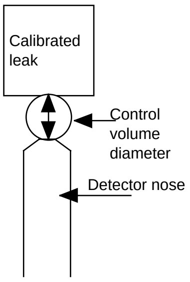

Figure 1 – Control volume of a portable leak detector (in E35-422)

A defined leak flow rate can be generated only based on the use of either calibrated leaks or standard leaks. The standard uses several calibrated leaks with leak flow rates ranging from 1 to 30 g/yr. Leak flow rates of these calibrated leaks shall be validated (see section 3).

Sensitivity Threshold
The performance of a leak detector is based first on the measurement of the minimum sensitivity threshold. Change in the measure or in the signal for different leak flow rates shall also be verified. Both parameters are checked by the standard E 35-422, the reference refrigerant being R-134a.

Operation of the leak detector is analyzed when located successively and 10 times in front of calibrated leaks set on different leak flow rates. Based on the repeatability of these it is then possible to conclude on the sensitivity or measurement scale of the leak detector and on its accuracy.

Selectivity
Some leak detectors are capable to detect any type of gas, some others any type of halogenated refrigerants, and some only a defined gas. This is called selectivity. Leak detectors that can detect any type of gases are also called non-selective. At present, this selectivity is not verified by standard E 35-422 because leak flow rates of different gases shall be generated, but only calibrated R-134a leaks could be standardized.

Recovery time
One practical parameter needs to be checked: the leak detector ability to recover its sensitivity once it has sniffed a high refrigerant concentration corresponding to a very high leak flow rate. Figure 2 presents the testing volume.

The standard group selected the value of 500 ppm for two reasons:
1) such concentrations can be found around significant leaks where gas pocket can be formed, in particular close to the ground;
2) for fluorinated safety fluids the practical limit is 1000 ppm, and this value has been divided by two.

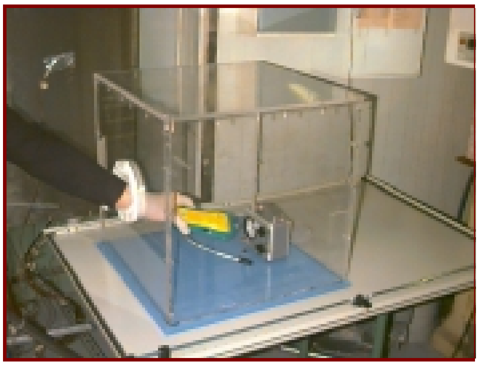
Figure 2 – Volume for test in polluted ambiance.

3. The standard E35-422

The standard qualifies performances of portable leak detectors by two series of tests, one is performed when the leak detector is fixed, the other one when the leak detector is in motion.

♦ **Calibration of calibrated leaks**

Two types of calibrated leaks are commercially available, but no standard process exists for the characterization of calibrated leaks. This is a true lack in the standard chain because the verification of the leak detector sensitivity is based on the accuracy of the generated leak flow rate.

Concerning helium, a primary standard is available at the NIST in the United States, one existed also in France, but it is not available at present. To the best of our knowledge, neither a device, nor a protocol exists for the verification of leak flow rates of HFC calibrated leaks.

♦ **Verification of leak flow rates of calibrated leaks**

The Center for Energy Studies had realized a confined chamber at atmospheric pressure, connected to an infrared spectrophotometer for continuous measurement of refrigerant concentration in this accumulation volume (see figures 3 and 4). This measurement tool was used for the validation of leak flow rates of calibrated leaks.

Figure 3 – Bench for the measurement of refrigerant leak flow rates.

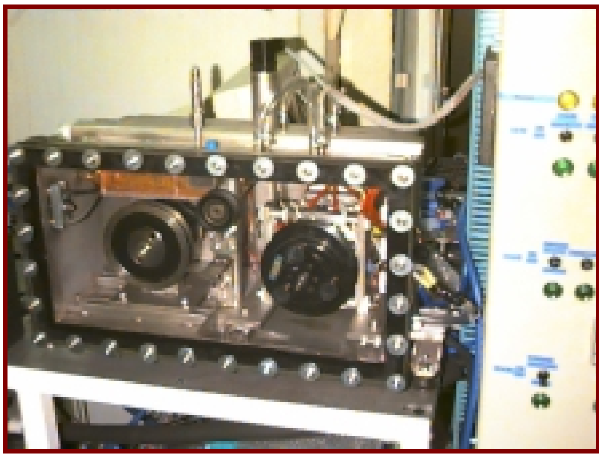

Figure 4 – The accumulation volume where the standard leak is located for calibration.

The sensitivity of the equipment is 1 ppm. The measurement scale has been verified by standard blends with ± 1 ppm accuracy. The refrigerant concentration in the accumulation volume can be calculated as well as its evolution along the time. Equation {1} [CLO97] permits to calculate the leak flow rate of calibrated leaks.

In equation {1}, the concentration variation along the time is expressed by the term *dC/dt* in p.p.m. by second. The ratio of the accumulation volume V_c to the controlled gas molar volume permits the calculation of the molar flow rate $\dot{N}$ (in mole/s).

$$\dot{N} = \frac{V_c}{V_{mol}} \frac{\partial C}{\partial t} \quad (1)$$

where:

V_c : accumulation volume in liter
V_{mol} : molar volume in l/mole
C : concentration variation in p.p.m.
t : time in second

The mass flow rate is calculated by conversion of the molar flow rate:

$$\dot{m} = \dot{N} \, x \, M \qquad (2)$$

where M is the molar weight in g/mole. Then g/s are converted in g/yr.

Calculations indicate that leak flow rate of 1 g/yr. can be checked with ± 10% accuracy and with ± 1% for leak flow rate of 10 g/yr. These values are appropriate for the validation of calibrated leaks used for the characterization of leak detectors.

The measurement equipment could become the reference system for the standardization of calibrated leaks. Presently, only R-134a calibrated leaks can be characterized. The characterization of other gases calibrated leaks needs additional measurement cells or, more generally a new design to make it multi-gases. Because of these constraints, only R-134a calibrated leaks have been verified and consequently, the Center for Energy Studies decided to characterize leak detectors with R-134a calibrated leaks.

- **Threshold sensitivity of leak detector in a fixed position**

The leak detector nose is placed in front of the calibrated leak outlet whose flow rate is set at a defined value (see Figure 5). Calibrated leaks are designed for leak flow rates varying from 1 to 5 g/yr., from 5 to 10 g/yr. and so on. Thus a series of 4 calibrated leaks are necessary to verify the leak detector response within a measurement scale of 1 to 30 g/yr.

The measure is repeated 10 times in front of each calibrated leak. If the result is identical 10 times, the sensitivity threshold is defined.

Figure 5 – Tests in a fixed position

- Threshold sensitivity of leak detector in motion

A device has been designed (see Figures 6 and 7) permitting to move the leak detector alternatively from left to right in front of the calibrated leak.

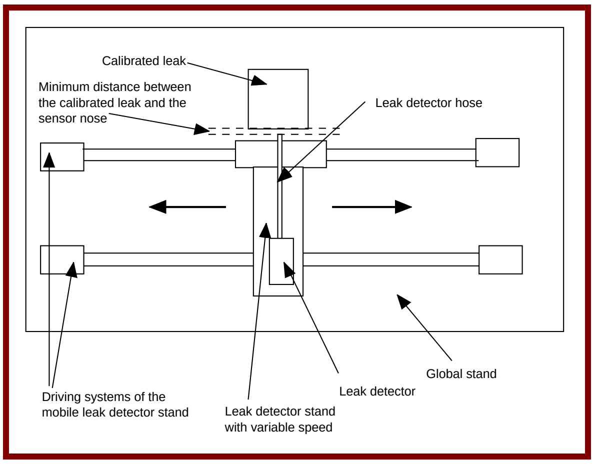

Figure 6 – Testing device for the characterization of leak detectors in motion (in E35-422)

Figure 7 – Experimental device for test in motion

The moving speed is 2 mm/s, the distance between the leak detector nose and the calibrated leak is 2mm. Tests are also repeated 10 times for several sensitivity thresholds.

Tests in fixed position and in motion are complementary and permit the characterization of leak detector from the viewpoint of its use.

4. Results

The observation of the general table of results of characterization of leak detectors permits several comments.

- 5 technologies of HFC leak detectors are available: Corona effect, platinum diode, ionization, ceramic permeation cell and ultra-son.
- All leak detectors tested are indicators. This is logical because of actual market requirements for low price. These leak detectors are mainly used for maintenance.
- All leak detectors tested are multi gases, fluorinated and chlorinated gases.
- In fixed position, **10** leak detectors out of 17 present minimum sensitivity of **2 g/yr.** and **14** out of 17 present sensitivity equal or lower to **2 g/yr.** This result is quite satisfactory. The regulatory requirement of a 5 g/yr. minimum sensitivity is rather conservative and the present market offer permits to fulfill this requirement.
- All leak detectors that present sensitivity in the range of 1 to 2 g/yr. in fixed position, keep it when they are tested in motion. When the sensitivity is the range of 3 to 5 g/yr. in a fixed position, it raises to 8 g/yr. when the leak detector is tested in motion.
- When tests are performed in polluted ambiance, several technologies fail the test. In some cases, very high concentrations yield to the detection cell destruction. However, some technologies do permit the test and to detect low leak flow rates in polluted ambiance.
- The ultra-son leak detector tested at the laboratory does not fulfill requirements of the French order of January 2000.

Note: any manufacturer and distributor of leak detectors and room controllers can request to the Center for Energy Studies of Ecole des Mines de Paris to characterize their equipment. Tests will be performed at no charge until June 30, 2000 and published in technical magazines (contact: phone 01 40 51 92 49, fax 01 46 34 24 91).

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