Refrigerant Containment Study

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AFCE Alliance Froid Climatisation Environnement

ADEME Agence de l'Environnement et de la Maîtrise de l'Energie

FINAL REPORT

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Executive Summary

Refrigerants are essential to the operation of refrigerating and air-conditioning plants.

Leakage of refrigerants, especially hydrofluorocarbons, has a direct and major impact on global warming due to their high global warming potential but also an indirect impact as the energy efficiency of the facilities is affected when the refrigerant load is less than the nominal load.

Cemafroid and IRSTEA, at the request of AFCE (Alliance Froid Climatisation Environnement http://www.afce.asso.fr/) conducted a study from September 2014 to May 2015 on the containment of refrigerating plants.

This containment study was conducted in France, a country which has taken a number of steps to reduce leakage well before the implementation of F-Gas in 2007.

The study was initially based on an in-depth literature review of good practices in containment on a wide range of equipment. An increase in publications was observed following the publication of the F-Gas Regulation in 2006, intensified by the valorisation of the REALZero(2009) and REALSkills (2011) projects.

This literature review enables to analyse a wide range of scientific and technical documents dealing with containment. Leaky components have been systematically identified.

In general, little scientific research has been published on this subject. Field studies are quite limited and old. It was therefore needed to perform a comprehensive update on practices regarding containment based on reliable data from the field.

The authors developed an overall approach to estimate leak rates based on the current literature and an online questionnaire sent to more than 500 refrigerating equipment installation/maintenance companies throughout France holding a qualification certificate. The response rate is in the range of 5 to 7%, which is consistent with the results of a similar study conducted in the UK (see Datasheet 7). This low participation rate can be explained by the fact that the containment of facilities remains a sensitive issue for both the refrigeration specialists and the facility owners, although the authors of the study established strict confidentiality agreements regarding the data supplied. In addition, the professionals who were contacted mentioned a lack of resources to complete the survey.

The results of the survey in terms of leakage rates are in line with the relevant literature. Drafting conclusions on non-accident related leakage rates was difficult because the refrigerant refills, as recorded on the worksheets, essentially relate to heavy failures causing significant leakage.

The survey shows that leakage rate depends upon the refrigeration technology used. Direct expansion systems are more subject to leakage. Components of refrigerating plant are not intrinsically leaky but assembly is subject to debate. Tightening torque is an important data given by the manufacturer and has to be respect by using a torque spanner.

Electronic leak detector is the most commonly used as detection device. It should meet strict accuracy and calibration requirements based on regulatory obligations and associated standards. It requires care, verification and maintenance in order to guarantee its accuracy. To be and remain efficient it should be correctly used and maintain.

One of the main report recommendations refers to the fact that the impact of leakage on the environment is due to, for a great extent, to few huge leakages rather than a multitude of small leaks (leakage rate of 5g/year or less). At the same time, it is more harmful for the environment to repair a

leakage with a leakage rate of 5g/year rather than letting it leak. It raises the issue of detection threshold of leak detector.

Leak tests should be standardized in terms of duration, completeness and reliability. In this regard, cross leak test should be widespread.

This overall approach was supplemented by site visits, which enabled:

- to identify which components were most susceptible to leakage;
- to identify good practices by sector of activity;
- to review maintenance contracts and the quality of maintenance services;
- to gain insight on the problems and issues both on the owners' and on the technical experts' sides.

A vast majority of refrigerating plant was not compliant with regulation concerning the monitoring of under pressure equipment (Pressure Equipment Directive). Compliant installations, facing periodic control, were significantly well maintained.

There are significant disparities in terms of maintenance depending on the sector. Whatever the sector, experts who performed audit have pointed out the quality of the information provided in operation sheets. Leakage causes are not always identified. Several leakages are not fixed before reloading the plant with refrigerant. Finally, technical visits allow us to promote containment good practices that worth considering more generally.

SUMMARY

Background

This containment study was conducted in France, a country which took a number of steps to reduce leakage well before the implementation of F-Gas in 2007:

- 1989: adoption of the “Refrigerants” agreement. This agreement was signed by the Minister of Environment, A*ssociation française du froid* (AFF, the French Association for Refrigeration), and users of substances within AFF’s National CFC Commission. In this agreement, distributors undertake to take spent refrigerants back from refrigeration technicians (with compensation). Refrigerants that are taken back by distributors are either regenerated or destroyed.
- 1992: publication of the Decree of 7 December 1992 (the Decree lays down, inter alia, the capability requirements to be met by personnel who handle refrigerants)
- 1993: the Agreement is reviewed to introduce the notion of a recovery package to be included in the price of every kg of refrigerant sold (cost sharing being freely determined by each of the distributors).
- 1998: implementation of the ADEME report, providing an emissions inventory and forecast under various scenarios for HFCs used as refrigerants.
- 2007: France was one of the first countries to implement F-Gas: Decree 2007-737 of May 7, 2007 relating to certain refrigerants used in refrigerating and air-conditioning equipment was repealed and replaced by Articles R543-75 to 123 of the Environmental Code regarding refrigerants used in refrigerating and air-conditioning equipment. This Decree is supplemented by:
    - Order of 7 May 2007: Leak Testing
    - Order of 20 December 2007: Annual Report
    - Order of 20 December 2007: Accreditation of Accredited bodies
    - Order of 30 June 2008: Issuance of Qualification Certificates
    - Order of 13 October 2008: Certificate of Capability
- 2007 ADEME launched a study foreshadowing the creation of the *Observatoire des fluides frigorigènes (*Refrigerant Observatory*)*
- 2008: •ADEME created the *Observatoire des fluides frigorigènes*. The IT reporting tool enables annual reporting by producers, distributors and accredited bodies to ADEME pursuant to the 20 December 2007 Order on Annual Reporting

The new F-Gas Regulation (517/2014) published in the Official Journal of 20 May 2014 regarding fluorinated greenhouse gases contains numerous provisions relating to the handling of fluorinated greenhouse gases (GHGs). It imposes the conditions for placing on the market certain products and equipment containing such gases or dependent thereon, and lays down the quantitative limits for placing HFCs on the market.

The new regulation highlights the need for the containment of facilities, the improvement of detection and immediate repair of leaks, and the keeping of logbooks on refrigerant-related service jobs.

Article 3 of the new F-Gas Regulation states in particular that operators of equipment containing fluorinated greenhouse gases must take precautions to avoid the accidental release (referred to as a "leakage" or “leak”) of these gases. Not only must the leaking equipment or facility be repaired rapidly, but the equipment or facility must also be inspected by a certified person within one month after the leak has been repaired.

The increasing scarcity of certain gases due to the phase-down of HFCs with a high Global Warming Potential (GWP) will cause a mechanical increase in the price of these refrigerants. Containment is therefore a major issue.

Scope of the Document

The purpose of this document is to provide an overview on the containment of refrigerating plants.

Target Audience

- Decision-makers in every field of application of refrigeration and air-conditioning;
- Employees of the French State and the European Commission who are aware of the problem of refrigerating plant containment;
- Business executives in charge of regulatory developments in relation to the choice of refrigerants;
- Professional associations of refrigeration and air-conditioning;
- Consultants of companies specialising in refrigerant environmental impact analysis;
- Non-governmental organisations specialised on environmental issues;
- International organisations such as UNEP;
- Training organisations.

Benefit to Readers

- Becoming aware of the importance of facilities containment in achieving environmental objectives;
- Knowing what are the major causes of leakage by technical architecture;
- Having the proper tools to improve the containment of a facility on a practical level throughout its service life;
- Having access to recommendations on good practice (documentary or technical) noted during the survey.

Keywords

Refrigerant, HFC, HFO, CO_2, ammonia, hydrocarbons, GWP, vapour compression, low-GWP refrigerants, F-GAS regulation, containment, leakage, detection, safety, heat-pump, air-conditioning, refrigeration system.

Abstract

Refrigerant leakages have an important direct impact on climate change due to their greenhouse gaseous properties and also an indirect impact because of the energy efficiency reduction of that equipment.

Cemafroid and Irstea, at the request of AFCE (Alliance Froid Climatisation Environnement http://www.afce.asso.fr/) were involved from September 2014 till May 2015 in a research program in order to develop a guidance document to help end-users or maintenance companies to detect and to minimize refrigerant leaks.

This study was based on a general literature review in order to list best practices for a large scope of equipment. A general approach to estimate leaks was developed in order to identify in real conditions, the precise origins of leakages. This approach includes an online questionnaire sent to more than 500 equipment owners/installers to collect refrigerant and maintenance data. This approach was completed by on-site visits to more than 20 different installations. The representative scope of equipment included in this study (HVAC, refrigeration equipment, etc.) have been evaluated in order to identify which component is commonly responsible for refrigerant losses or which procedure of containment has to be promoted.

This report presents the result of this study which is particularly important in the field of refrigerant especially HFC ones where the new regulation (F-Gas in Europe) reinforces all initiatives to limit uncontrolled emission of the greenhouse gas.

1. Background of the Study

1.1. Purpose of the Report

AFCE is an association governed by the French law of 1901 which promotes the responsible use of refrigerants. As such, the study reviews the regulatory work relating to HFCs and regarding all refrigeration techniques in general.

Refrigerants are essential to the operation of refrigerating and air-conditioning plants. Leakage rates for many applications are little known, other than by their owners. Whereas factory-charged equipment are tested by the manufacturer and presumed to be leak-tight, plants which are assembled and then charged onsite, on the other hand, may be subject to leakage rates greater than 30% per year. A recent study has shown that inherent leak-tightness of the components cannot be questioned but that the suitable containment of a plant depends on how the components are implemented, and then how the facility is operated, and its degree of obsolescence.

The study focuses on the French territory and on plants charged with halogenated fluids (HCFC, HFC) but also so-called natural fluids[1] (CO_2, Ammonia, and hydrocarbons). Factory-charged equipment are also reviewed.

1.2. Overview of the organisations who carried out the study

The consortium who initiated the study consists of Cemafroid, a centre of expertise in the cold chain, and IRSTEA, a research centre in refrigeration engineering.

Both entities have complementary skills. Their personnel have extensive knowledge of refrigeration systems, a world reputation on refrigerants, and a network of relations with all the parties involved: Ministries, the European Commission, chemical engineering companies specialised in refrigerants, major air-conditioning and refrigeration companies, large user companies, and professional trade unions.

Furthermore, the lines of activity of these organisations are not related to the manufacturing and marketing activities of the technologies reviewed by the study, thus ensuring that the state of the art techniques are assessed in an impartial and independent way. The experts who took part in the study are listed in Appendix 6.

[1] So-called « Natural Refrigerants» are described as such since they have no impact on the Environment but they remain chemically synthetized compounds.

2. Methodological Approach of Study

2.1. Segmentation by line of activity and by refrigeration system

The overall refrigeration and air-conditioning applications can be broken down into 7 main fields of application:

- Domestic refrigeration;
- Commercial refrigeration;
- Refrigerated transport;
- Industrial refrigeration (food industry);
- Air-conditioning systems;
- Heat pumps and
- Mobile air-conditioning.

Within these fields, various types of plants or equipment are used, which can be distinguished in that they use different technologies (e.g., centrifugal compressor, displacement compressor), different system structures (direct expansion system, indirect system including one, or even two cooling loops), and different refrigerants.

As the purpose of the study was to examine the containment of refrigerating plants, a list of refrigeration systems and sub-segments having common containment rules was drawn up. Each sub-segment relates to one or more fields of application. In the 7 main fields of applications, 4 refrigeration systems and 10 segments were identified, and are listed in Table 1.

TABLE 1. TYPES OF REFRIGERATING PLANT ARCHITECTURES

Refrigeration system	Segments	Fields of application
Factory-loaded hermetic system	Monoblock equipment	Domestic refrigeration, Commercial refrigeration, heat pump, air-conditioning (window, console, mobile type), Rooftop
Production plant	Dry expansion/remote condensation	Food Industry, Chillers, Commercial refrigeration (remote refrigeration cabinet)
	Dry expansion/ condensation in machinery room	
	Flooding/remote condensation	
	Flooding/ condensation in machinery room	
On-board system	Motor driven system	Refrigerated transport
	Independent system	
	Mobile air-conditioning	Air-conditioning for automobile, train, bus
Splits	Low capacity (< 17,5kW)	Cold room, air-conditioning, heat pump
	High capacity (>17,5kW)	

2.2. Format of Bibliographic Reference Summary Sheets

Bibliographic references are taken from the databases of Cemafroid and Irstea, and scientific databases such as ScienceDirect (ELSEVIER) or Fridoc (International Institute of Refrigeration).

Title	Document Title		
Date	Date of publication	Sheet no.:	1
Author		Affiliation:	
Nature:	Type of document: scientific paper, technical article, study report, , etc.		
Source:	Publishers		
Summary:	Abstract of document		
Field of Application	As defined in the segmentation		
Refrigerant:	Refrigerant's ASHRAE classification if available; if not, refrigerant family		
Type of machine:		Hermetic system:	
Recommendations			
Notes			

2.3. Online Survey

An online survey (see template in Appendix 1) was conducted starting in October 2014 among 500 participants to identify the causes of leakage according to the field of application and the refrigeration system as defined in the segmentation.

To preserve the representativeness of the survey, special care was taken in the selection of facilities according to the line of activity and the refrigeration system.

The authors of the study also offered the participants strict confidentiality agreements on the data supplied.

2.4. Inspection Sheet

To supplement the information obtained during the online survey, Cemafroid selected a number of plants for on-site visits. The visits were performed by auditors having refrigeration expertise. The template for the visit report can be found in Appendix 2.

During these visits the technical documentation of the facility was examined together with the job sheets. Where possible, experts examined the maintenance contract to check the inspection frequency and the points periodically checked.

3. Bibliography and Overview of the Current Situation

3.1. Nature of the Documents Reviewed

The full list of the documents reviewed is given for reference.

3.1.1. Document Contents

The documents reviewed relate to various topics:

- Leakage rate calculation method;
- Leakage rate data;
- Leakage rate measurement method;
- Good practice guide;
- Recommendations;
- Environmental impact.

The breakdown is given in Table 2.

TABLE 2. TOPICS ADDRESSED IN THE DOCUMENTS REVIEWED

Sheet no.	Leakage rate calculation method	Leakage rate data	Measuring method	Good practice guide	Recommendations	Environmental impact
1	X	X	X		X	X
2	X			X	X	
4	X	X	X	X	X	
5		X			X	
6		X				
7		X				
8	X	X				X
9	X	X				
10						
11	X	X				
12	X	X	X			X
14		X			X	
15	X					X
16					X	
17	X	X	X			
18		X				
19		X	X			X
20		X				
21					X	

Sheet no.	Leakage rate calculation method	Leakage rate data	Measuring method	Good practice guide	Recommendations	Environmental impact
22		X				X
23		X		X	X	
24						X
25	X		X			X
26						X
27	X	X	X		X	X
28	X				X	X
29						X
30	X					X
31	X					
32						
33				X	X	
34				X	X	
35	X			X	X	X
36				X	X	
37				X	X	
38	X				X	X
39		X		X		
40	X	X			X	
41						X
42	X			X	X	
43				X	X	
44			X			X
45					X	X
46	X					X
47				X	X	
48						
49						X
50						
51		X			X	X
52		X				X
Total	19	20	8	11	21	22

3.1.2. Typology

Most of the documents reviewed are scientific papers. There are also several study reports relating to the containment of refrigerating plants, and numerous good practice guides (several of these guides are taken from the REAL SKILLS Europe project).

TABLE 3. NATURE OF DOCUMENTS

Nature of document	Number
Conference paper	1
Journal article	1
Scientific paper	18
Good practice guide	10
Technical Note	2
Presentation	4
Study report	11
Web site	1
Data summary	1

40% of contributions are from three organisations:

- Institute of Refrigeration (22%);
- Cetim (8%);
- Ecole des Mines (10%).

17 articles (34%) describe a specific type of machine, 15 relate to direct expansion, and 2 relate to indirect cooling.

Facts to remember

In general, few publications address the topic of refrigerant containment in refrigerating plants. Field studies are few and rather old. It was necessary, therefore, to provide an assessment on the containment of refrigerating plants based on these field collected data.

3.1.3. Date of Publication

A significant increase in publications on the topic of containment was observed after F-Gas (2006) was issued, intensified by the valorisation of the REALZero(2009) and REALSkills (2011) projects.

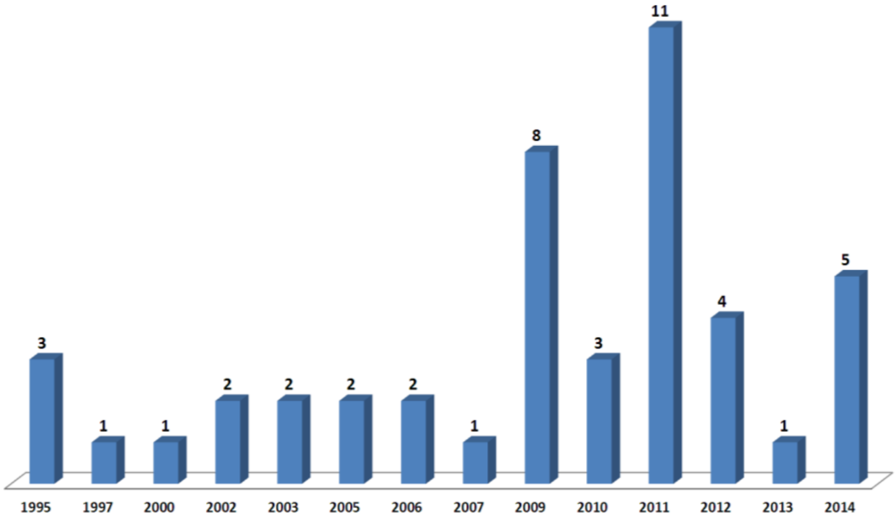


FIGURE 1: BREAKDOWN OF DOCUMENTS BY DATE OF PUBLICATION

3.2. Leakage Theory & Main Detection Methods

This section describes the theoretical elements taken from the publications referred to in this report.

3.2.1. Leakage Types

A leak or leakage is the transfer of a fluid (gas or liquid). There are 2 types of leakage:

- Permeation leakage: this is a leak that occurs through a porous wall;
- Interfacial leakage: this is a leak due to a passage (a crack, a scratch, a foreign body creating a passage, under-tightening of 2 assembled components, etc.).

In general, permeation leakage is neglected in comparison to interfacial leakage, because the migration of a fluid is often much slower, except for leaks in hoses, which often have elastomer walls that may become porous with time.

3.2.2. Main Indirect Methods of Leak Detection

Article 7 of European Regulation no. 1516/2007 proposes a list of indirect methods:

- measurement by pressure drop;
- measurement by pressure build-up;
- monitoring of the plant’s operating parameters;
- use of an atmosphere detector.

These methods can identify the presence of leakage, without locating it.

Measurement by pressure drop

In order to determine the overall leak-tightness of the system, prior to being evacuated and charged the plant is pressurised to maximum operating pressure using an inert gas, commonly nitrogen. The changes in pressures are monitored, but also the changes in temperature. In fact, a change in temperature may influence the gas pressure, and therefore lead to an incorrect result.

The table below shows the pressure variation as a function of temperature (volume is constant) for nitrogen:

TABLE 4. PRESSURE VARIATION VS. TEMPERATURE FOR NITROGEN

Ambient temperature (°C)	Pressure (bar)
20	25
21	25,09
22	25,18
23	25,27
24	25,36
25	25,45

This table shows the importance of temperature monitoring, as ambient temperature vary during the day and has an effect on the refrigeration system. A difference of 1 K causes a pressure variation of 90 mbar. During the study, tests were performed in the IRSTEA laboratories to check the pressure drop detection thresholds (see Section 4.1)

Measurement by rising pressure

The rising pressure measurement is performed following vacuum of the installation. Once the desired vacuum has been achieved, pressure gauge valves are closed, the vacuum pump is stopped, and the pressure is checked to see if it rises. This method, however, poses the problem that if the plant has a leak, air will be let into the installation.

Monitoring of Operating Parameters

Use of pressure gauge and thermometer, although having a high level of uncertainty, allows routine functional testing to be performed.

New alternatives, based on the aforementioned indirect methods are now available on the market with an additional review of plant operating parameters such as evaporation and condensation temperatures, overheating, and subcooling.

Use of an atmosphere detector

Use of an atmosphere detector is one of the indirect methods of European Regulation no. 15 16/2007 Articles 7, Sections 3. In France it is recommended by the Order of 7 May 2007. European Regulation no. 842/2006 (Article 3, Section 3) imposes the use of a fixed detector for plants over 300 kg of refrigerant charge.

The current design of atmosphere detectors requires that they are placed near a leak. Consideration should also be given to how the gas moves (dependent on the gas density) through the ambient air in order to position the fixed detector in the most suitable way.

The equipment should be more than 50 cm away from a fan, and far from heat sources. An atmosphere detector should not be placed in a draught. Two constraints are therefore to be considered: on one hand, the quality of detection, which requires the room to be air-tight and free of draughts and, on the other hand, the constraints linked to EN378 which imposes an air renewal system adapted to the refrigerant being used and its degree of toxicity.

3.2.3. Main Direct Methods of Leak Detection

There are numerous methods of locating a leak. Some can be used to perform a measurement, and therefore to estimate the local leakage level, others to indicate whether a threshold, either predetermined or estimated, has been exceeded (in the range of 5 g/yr.). During the study, tests were performed in the Cemafroid laboratories to check the detection thresholds of leak detectors (see Section 4.2)

The European F-Gas regulation refers to the following direct methods: use of gas detection devices, fluorescent liquids more readily visible with UV rays, colorants, foaming solutions or soapy water.

These methods are associated with different types of techniques or apparatus:

- Measuring detector: a complex, costly apparatus which is used to locate, detect and estimate the value of the leak detected;
- Electronic detector: an apparatus that detects and locates a leak by showing whether a determined leakage value has been exceeded;
- Foaming product or soapy water, which are used to locate a major leak;
- Fluorescent fluid, which is used to locate a leak by observation of a visible spot using a UV lamp.

The following table lists the methods most commonly used to leak test a refrigerating plant.

TABLE 5. COMPARISON OF DETECTION METHODS

Method	Benefits	Drawbacks
Leak testing spray/soapy water	Simple, convenient and cheap. Ideal for detecting major leaks and allowing rapid maintenance of the equipment	Characteristics and sensitivity not easily reproducible
Fluorescent additive (injected into the system) detected by UV lamp	Simple to use: fill up, then examine with UV lamp	Impossible to ensure that the tracer gas has been applied to places likely to leak. This technique may cause compressor damage if the oil is not monitored and replaced regularly
Electronic leak detector	Simple and convenient. Meets statutory requirements if qualified under EN 14624.	Equipment may be fragile and should be periodically calibrated. Beyond the detection threshold, unable to distinguish between a major leak and a minor leak
Measuring detector	Equipment is accurate. Indicates leakage level. Meets statutory requirements	Costly. Requires heavy training before it can be used.

Facts to remember

There are several leak detection methods, indirect ones and direct ones. Indirect methods are generally used when a plant is being commissioned, to check its overall containment or as a method to monitor the operating parameters of the facilities. These methods are used to confirm the presence of leakage without locating it.

Direct methods are essential for locating leakage. The electronic leak detector is the most widely used detection equipment. It must comply with specific sensitivity and calibration requirements imposed by legislation and related standards. It requires proper care, inspection and maintenance to ensure its accuracy. To be and remain effective the detector must be properly used and maintained.

3.3. Summary of the available results on the environmental impact of leakage

3.3.1. Refrigerant Bank

Document [52] provides an overview of the global bank and emissions of refrigerants. HFCs are shown to dominate the market with 75% of the bank (including 40% for R134a).

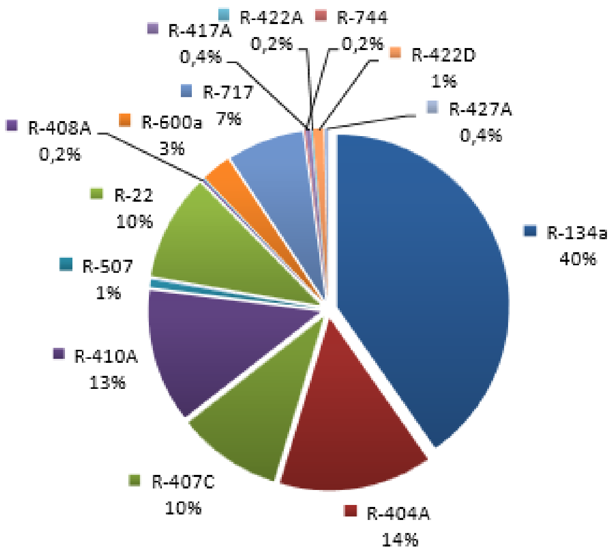


FIGURE 2. DISTRIBUTION OF REFRIGERANTS FORMING THE REFRIGERANT BANK OVER METROPOLITAN FRANCE.

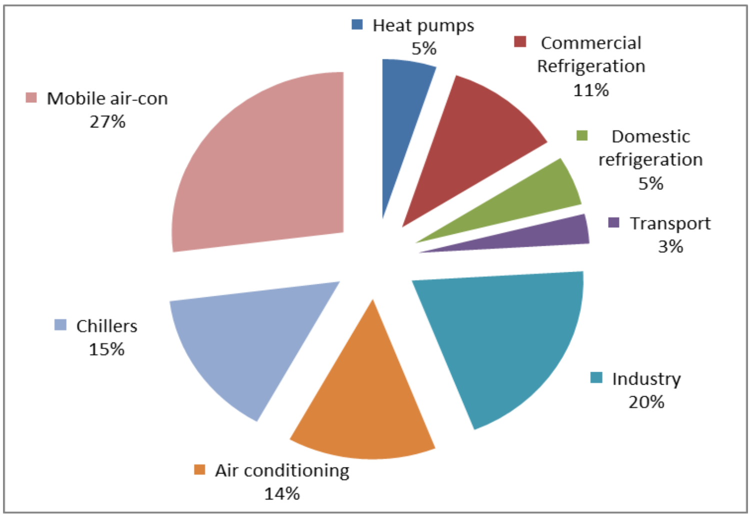


FIGURE 3. DISTRIBUTION OF THE REFRIGERANT BANK BY SECTOR

3.3.2. Direct Emissions

Document [52] provides fugitive emission rates by field and sub-sector.

Field	Sub-Sectors	Average Charge	Fugitive Emission Rate
Domestic refrigeration	Refrigerators	46 g	0.01%
	Freezers and combos	60 g	0.01%
Commercial refrigeration	Supermarket	0.2 kg/m2	30%
	Hypermarket	0.14 kg/m2	35%
	Hermetic units for small businesses	0.3 to 3kg	1%
	Condensing units found in small businesses	2 to 20kg	15%
Refrigerated transport	Driving pulley units used in road transport	1.6kg	20%
	Self-contained units	6.5kg	11%
Food Industry		100 kg to a few tons	15%
Water Chillers	Small capacity	0.3 kg/kW	10%
	Medium and high power	0.2 kg/kW	5%
Air-conditioning	Individual, mobile, window, or console type	0.5 to 1kg	2 to 5%
	Individual, small capacity split	1.5 kg	5%
	Self-contained (VRF)	9kg	10%
	Self-contained (Rooftop, medium/high power split)	5 to 30kg	6 to 10%
Heat pumps	Residential	2.5 to 15kg	2 to 5%

TABLE 6. FUGITIVE EMISSION RATES BY FIELD AND SUB-SECTOR

This table is taken from *Inventaires des Emissions des fluides frigorigènes FRANCE et DOM COM Année 2012*, Armines, ERIE, Décembre 2013

(Inventory of Refrigerant Emissions from FRANCE and overseas territories in Year 2012, published in December 2013)

3.3.3. Indirect Emissions

In the event of leakage, impact on the greenhouse effect is due not only to the emission of refrigerants but also to the indirect effect of the facility's lower performance. The proportion of the refrigeration machine's indirect effect, therefore, is substantial when leakage occurs. However, a less than 20% variation in charge has little impact on energy consumption. Higher than this, overconsumption is significant [26].

I.N. Grace et al. / Applied Thermal Engineering 25 (2005) 557–566

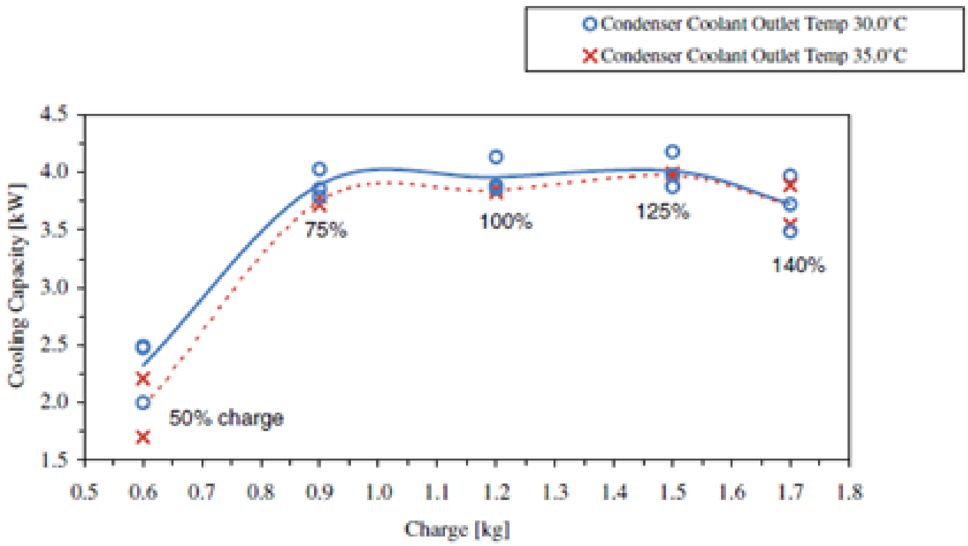


FIGURE 4 REFRIGERATING CAPACITY VARIATION VS. FLUID CHARGE

On the above Figure, it is shown that for a 25% loss in charge, the capacity is decreased by 14%, and for a loss of 50%, a 40% decrease in refrigerating capacity can be observed.

It should be noted that the average emission in CO_2 eq. of a heat pump in the UK is estimated to be greater than or equal to that of a fuel combustion heating solution [6].

Facts to remember

The global leakage rate for all refrigerants appears to be in the range of 17%. Leakage rate data vary widely according to the documents reviewed, especially for commercial refrigeration, where leakage rates vary from 6.5% to 30% depending on the publications. When leakage occurs, impact on the greenhouse effect is due not only to the emission of refrigerants but also to the indirect effect of the facility's lower performance.

3.4. Summary of existing guidelines and recommendations

3.4.1. Main Causes of Leakage

The level of leakage depends on the refrigeration technology. Direct expansion systems are more susceptible to leakage.

Heat stresses (evaporator defrosting period) are the cause of major fatigue and increased risk of leakage at evaporator return bends.

Mechanical stresses are high in refrigerating plants. Liquid hammering or repeated vibration may cause pipe ruptures leading to severe leakage.

3.4.2. Aggravating Factors

The detection systems in place do not always warn the plant maintainer, any rapid onsite response thus being delayed.

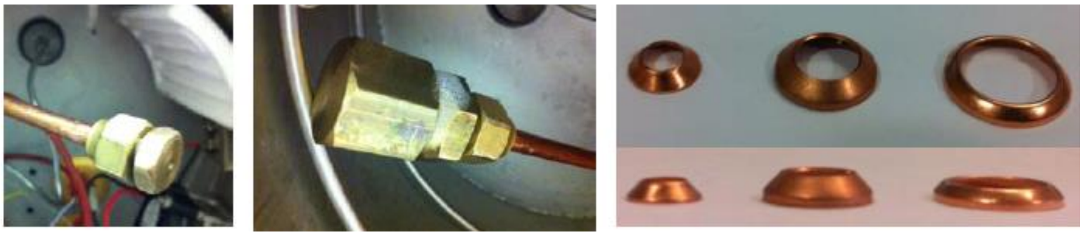
The funds allocated to maintenance are not always sufficient to provide quality maintenance.

3.4.3. Main Leaking Components in a Refrigerating Plant

By definition there is no such thing as absolute dynamic sealing: it is an ideal to which technology is aspiring.

Many documents agree with the results of the European REALSKILLS Europe Project. Few documents provide leakage rates by component. Document [16] indicates that flare joints are responsible for 50% of the losses.

The AHRTI Report [1] highlights the problem of the tightening torque for these connections. Tightening test results are shown below:



3/8 flare joints under test	½ flare joints under test	3 sizes of joints

FIGURE 5. ILLUSTRATION OF A TIGHTENING TEST

T [°C]	Pressure [kPa]	Torque [Nm]	Leak Flow Rate [g/yr] no.2	Leak Flow Rate [g/yr] no.3
50	1318	10	Huge leak	Huge leak
		20	0.057	Huge leak
		30	0.020	12.8
		40	NC	0.072

TABLE 7. LEAK FLOW RATES OF FLARE JOINTS AS A FUNCTION OF TORQUE (TAKEN FROM THE AHRTI REPORT [1])

High leakage rates occur when the optimum tightening torque has not been achieved. Tightening torques also depend on how the joint was made.

The following classification was established according to how often the leak-causing components were mentioned in the documents:

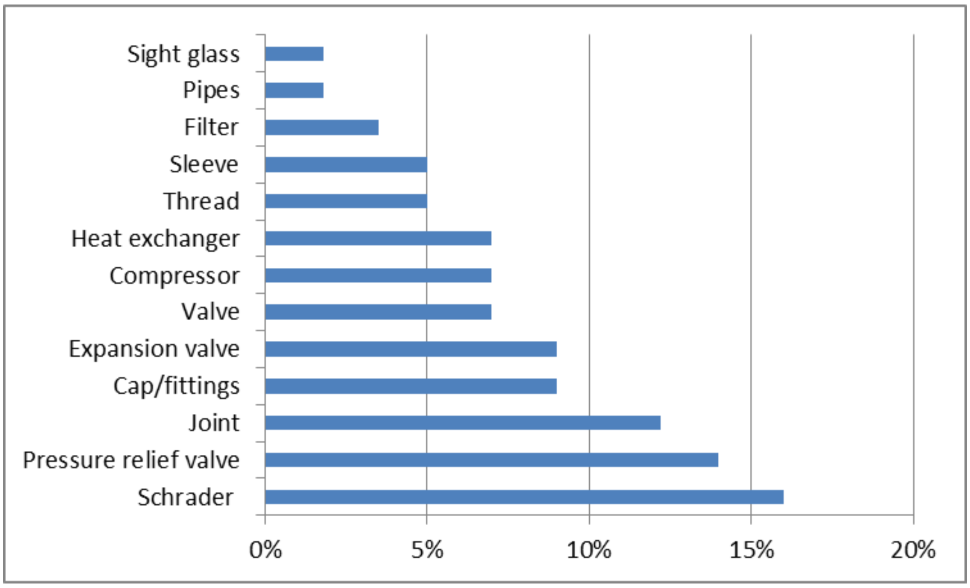


FIGURE 6. CLASSIFICATION OF LEAKS BY COMPONENT ACCORDING TO OCCURRENCE IN THE REFERENCED DOCUMENTS

This classification is complementary to the illustrated guide to 13 common leaks shown hereafter.

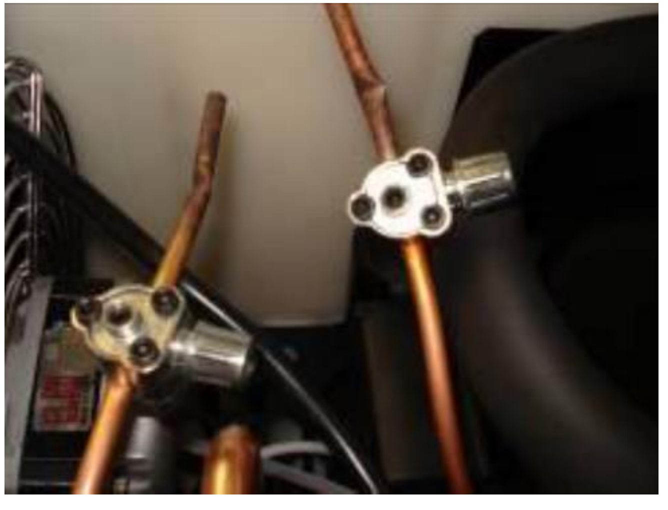
Facts to remember

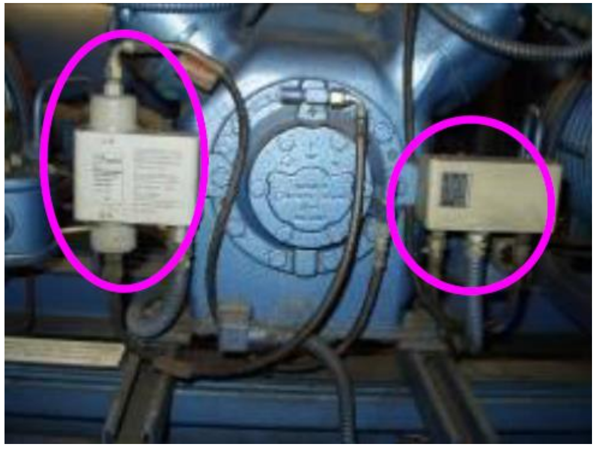
The level of leakage depends on the refrigeration technology. Direct expansion systems are more susceptible to leakage. The components that make up assemblies used in refrigeration and air-conditioning are not inherently leak-prone. What is questioned is how they are assembled. The tightening torque is an important piece of information supplied by the manufacturer, which must be complied with by using a torque wrench. Following analysis of the bibliographic references, a classification of the components having caused the largest number of leaks was established according to how often they occurred in the documents. This classification corresponds to the Guide to Good Practice published in the context of the European Real Skills Europe [33] Project and presented hereafter.

Equipment/location of the leak	Likely cause	Solutions
Shut-off valve 	Wear of the packing gland between the valve body and spindle shaft as it becomes compacted with age	Ensure that the gland is tightened Wrap the valve with a damp rag while brazing Always cap valves
Schrader valve 	Valve core damaged during brazing Deterioration of the internal seal over time Cap not fitted or has no O-ring seal	Remove the core when brazing the fitting in; ensure the valve body has cooled before moving the core Use the correct tool to replace and tighten the core

Flare connection 	Loosening of the flare nut due to high thermal expansion due to wide temperature variation (especially for those at the outlet of expansion valves) Poor flare preparation (causing leakage from initial installation) Over-tightening, leading to damage at the copper flare face and the flare nut Under-tightening of the flare connection	Where possible, avoid using flare connections. If they cannot be avoided: Use flare solders adaptors. Ensure the copper seal is located correctly Carefully prepare the flare, cutting and de-burring the pipe using appropriate tools, Check the flare size so it does not foul the flare nut on the pipe Lubricate the flare and nut with a small amount of refrigeration grade oil Use a torque wrench to tighten to the setting provided by the equipment manufacturer
Mechanical joints and flanges 	Incorrectly prepared joint, gasket not replaced Uneven tightening of flanges Incorrect torque used for tightening bolts	Do not use PTFE on HFC refrigerants. Use an appropriate thread sealant. When replacing gaskets on flanges, remove all the old gasket material from the surface before applying the new one Tighten flanges down applying the ‘opposites’ rule until the flange is seated correctly Use a torque wrench

Pressure-relief valve (PRV) and fusible plug (over-pressure protection) 	Fusible plugs: wide temperature and/or pressure variations weaken the bond between the core and the plug PRV does not reseat when the pressure drops	Avoid using fusible plugs, replace them with PRVs Always leak test PRVs. Use PRVs with a discharge indicator
Shaft seal (open type compressors) 	General wear of the shaft seal over time, increased oil loss from the slip ring Lubrication failure Incorrect fitting of a new shaft seal Incorrect shaft alignment	Regular observation of the oil leakage rate into shaft seal collection vessel to check oil loss does not increase. Leak testing of the shaft seal with the compressor switched off Following the proper procedure when replacing the shaft seal

Condenser 	Shell and tube condenser: Corrosion of the copper and mild steel if the water circulating in the tubes is not treated Air-cooled condenser: Corrosion due to aggressive air. Impact damage due to foreign bodies on the fin block. Vibration causing premature failure of the tube bundle	Regular observation of corrosion points. Periodically check coolant: (chemical dosing) Position air condensers on a level base Check that fans are balanced to limit vibration
Line tap valve 	Poor fitting of the line tap onto the pipe, or being fitted to badly formed or flattened pipe work. Use of the wrong size line tap Loosening of the line tap valve due to vibration	Leak test line taps and replace if possible

Pressure switch 	Vibration causing the pressure coupler to split or damage to the pressure switch Pressure coupler chafing Rupture of the switch bellows due to vibration or hydraulic action Failure of the flare connection Poorly supported or fixed pressure switch	Use flexible pressure couplers where possible (stainless steel braided type offer a high degree of strength and mechanical protection. Make sure pressure couplers do not rub or chafe on other pipes or vibrating surfaces. Ensure the switch is correctly supported / fixed Connect the switches to minimise the transfer of vibration into the switch
O-ring 	Hardening or flattening, especially when subjected to extremes in temperature Leakage after retrofitting because of a different reaction to the new oil	Check (for roundness and flexibility) and change the seal if possible Oil seals before fitting them Ensure the seal is suitable for the system oil and refrigerant

Capillary tubes (pressure couplers and expansion devices) 	Chafing due to insecure fixing Leakage where a capillary tube expansion device enters / exits the suction line	Check capillary tubes are firmly located and cannot chafe
Return bends on evaporators 	Corrosion due to chemical action on the return bends of heat fin blocks Surface defect. Aggressive environments accelerate damage and cause leakage	Leak test return bends If evaporators are to be replaced, specify more resistant materials with protected or chemically treated heat fin blocks

4. Metrological Analysis of Detection Thresholds

4.1. Metrological analysis of needle and digital pressure gauges

One of the main tools of the refrigeration technician is the pressure gauge. A pressure gauge is used to perform a functional test, with the help of a thermometer.

By means of those two instruments, the refrigeration technician is able to check that a refrigerating plant is functioning properly. However, these measuring instruments, especially the pressure gauge, are not very accurate and may lead to incorrect interpretation.

To illustrate the interpretation of measurements, IRSTEA laboratory tests were conducted to determine the influence of the measurement accuracy of needle and digital pressure gauges and its consequences on the assessment of leakage in a facility.

4.1.1. Testing Conditions

Testing was conducted in the IRSTEA laboratory. The purpose was to check the detection threshold of a needle type pressure gauge and a digital pressure gauge. These pressure gauges were connected to laboratory equipment capable of increasing or decreasing the pressure as desired, and reading the values on a digital screen (Druck PC6–IDOS standard).

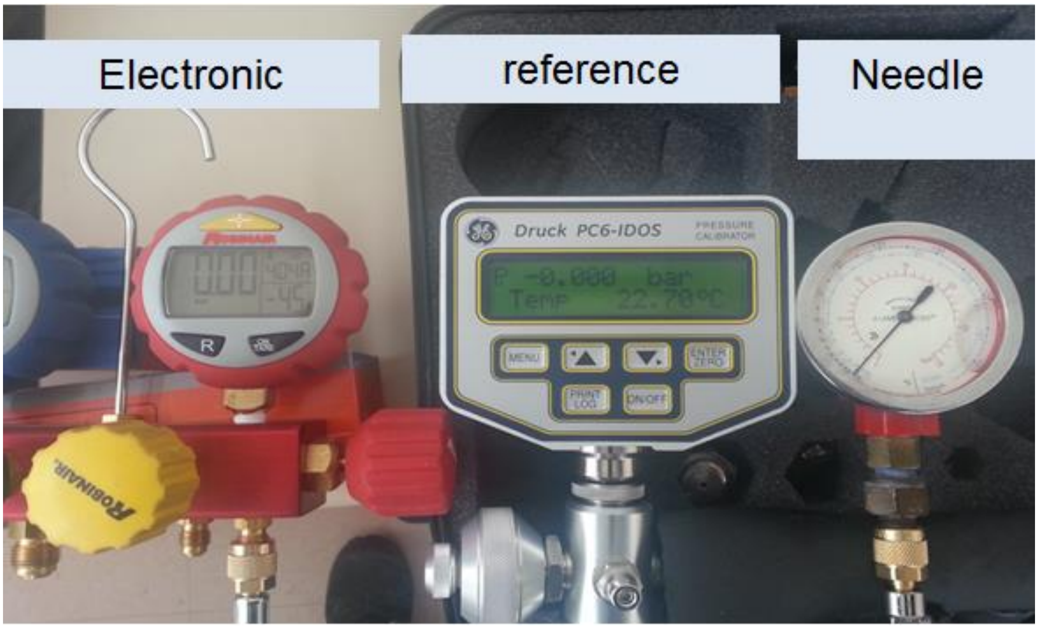


FIGURE 7. PICTURE OF THE TESTING DEVICE

4.1.2. Equipment

Three pieces of equipment were used: one digital pressure gauge, one needle type pressure gauge, and one pressure standard, whose characteristics are shown in Table 7.

TABLE 8. CHARACTERISTICS OF PRESSURE GAUGES USED IN THE TEST

	Digital	Needle	Standard reference
Operating range	0 à 55,15 bar / 0 à 800 psi /	-1 à 30 bar	-1 à 35 relative bar
	0 à 56,25 kg/cm2 / 0 à 5,515 MPa		
Accuracy (confidence interval)	±1% of full range from 0 to 34.47 bar	Class 1= ±1% of full range	Class 1= ±0.025 of full range
	(0-500 psi) range	i.e. : ±300 mbar	i.e. : ±8,75 mbar
	±2,5 % full pressure de 34,47 bar à 55,15 bar (500-800 psi) range		
Resolution (possible deviation between two readings)	0,05 bar / 0,5 psi / 0,05 kg/cm2 /	1 bar	1 mbar
	0,005 MPa / 0,1 inHg / 0,5 mmHg		
	Temperature : 1 °C / 1 °F	from -60°C to -40°C : 10K from -40°C à +20°C : 5K A Above 20°C : 1K	Temperature: 1 K
Price	300 Euros	200 Euros	4,000 Euros

4.1.3. Measurement Result

A pressure of 10.199 bar was applied. Pressure was dropped to 74 mbar, this pressure drop corresponding to the detection threshold of the digital pressure gauge.

In the picture below, a 74 mbar pressure drop translates into a 50 mbar pressure drop on the digital pressure gauge. This is due to the pressure gauge resolution, which is 0.05 bar.

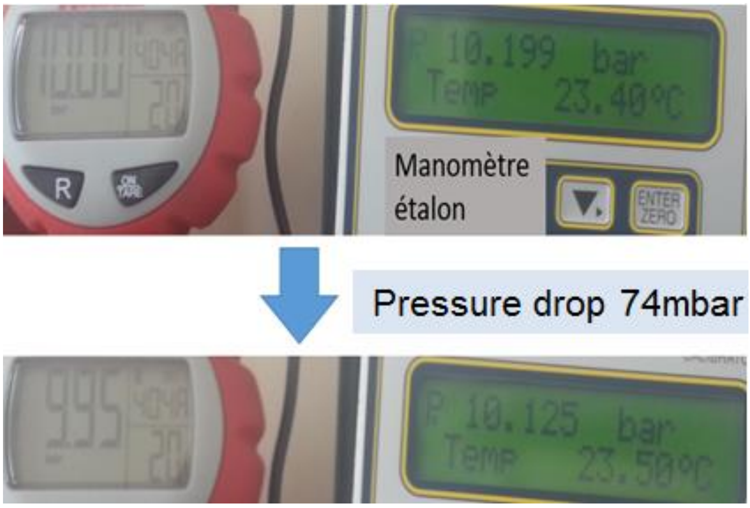


FIGURE 8. RESULT WITH A DIGITAL PRESSURE GAUGE

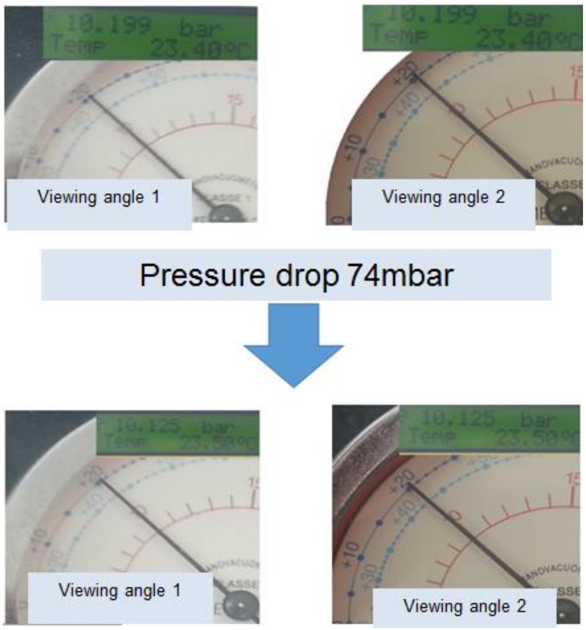


FIGURE 9. RESULT ON THE NEEDLE TYPE PRESSURE GAUGE WITH TWO DIFFERENT VIEWING ANGLES

As can be seen in the above figure, the problem is due to the resolution, on one hand, but also to the operator's misinterpretation, plus the error related to the class of precision of the equipment (here, Class 1 i.e., ±1% of the full range).

- A pressure of 74 mbar does not appear on the pressure scale (one-bar resolution);
- A slight decrease can be seen when looking at the temperature scale.

4.1.4. Interpreting the results on a real-case R404A refrigerating plant

To understand what this nitrogen pressure drop represents compared with an R404A pressure drop, the following assumptions are made:

- **R04A refrigerant** is in gaseous state;
- R404A is assumed to have a **leakage rate 7 times less** than that of nitrogen (molar mass ratio), therefore this example will use a **10 mbar leak** as the initial hypothesis;
- conditions are ideal, the temperature is **20°C** and does not vary;
- the properties of the refrigerant are calculated using **Solvay fluor's refcalc;**
- P_1= initial pressure; P_2= final pressure;
- m_1= initial mass; m_2= final mass;
- v''_1= initial specific volume, v''_2= final specific volume;

Given a 100 litre volume filled with R404A (homogeneous mix), the initial pressure is 8 bar. 24 hours later, the pressure is 7.99 bar (in practice, a 25 kW plant may have a volume of 100 litres).

The fluid mass can be determined using fluid properties:

For P_1=8 bars, and 20 °C, the mass of 100 L of R404A is:

$$m_1 = \frac{V}{v''_1} = 3,766kg$$

For P_2=7.99 bars, and 20 °C, the mass of 100 L of R404A is:

$$m_2 = \frac{V}{v''_2} = 3,7608kg$$

The loss in mass, therefore, is $m_1 - m_2 = 5g/24h$

That is, 2 kg of refrigerant over 1 year.

Facts to remember

As part of the study, laboratory tests were conducted to determine the influence of the measurement accuracy of needle and digital pressure gauges and its consequences on the assessment of leakage in a facility.

These tests have shown that despite ideal conditions, needle type pressure gauges can only detect leaks equivalent to 2 kg/yr. on a plant which may contain up to 20 kg of R404A refrigerant.

This detection method therefore cannot be used as a substitute for leak testing by direct methods, to be performed on the entire plant, both when a plant is commissioned and during routine inspection.

4.2. Influence of leak detector operating conditions

During the study, Cemafroid metrologists sought to examine how the method of use of the leak detectors influenced the performance of the measuring instruments.

4.2.1. Testing Conditions

The study was conducted within the Cemafroid Metrological Laboratory

Lab data:

- Temperature: 21.3 °C (+/- 0.1);
- Humidity: 29.1% (+/- 0.1);
- No draught.

4.2.2. Equipment

- 1 calibrated leak belonging to TECNEA Italy.
    - Type: FET-115
    - Gas: R-134a
    - Serial number: 016769
- 2 leak detectors belonging to Cemafroid – D-TEK Select.
    - EQT-FRE-169
    - LG 11-030

- One meter

Note: the calibrated leak used was calibrated at 5 g/yr. only. Results are based on the user documentation and are given for information only.

4.2.3. Diagram of the Device

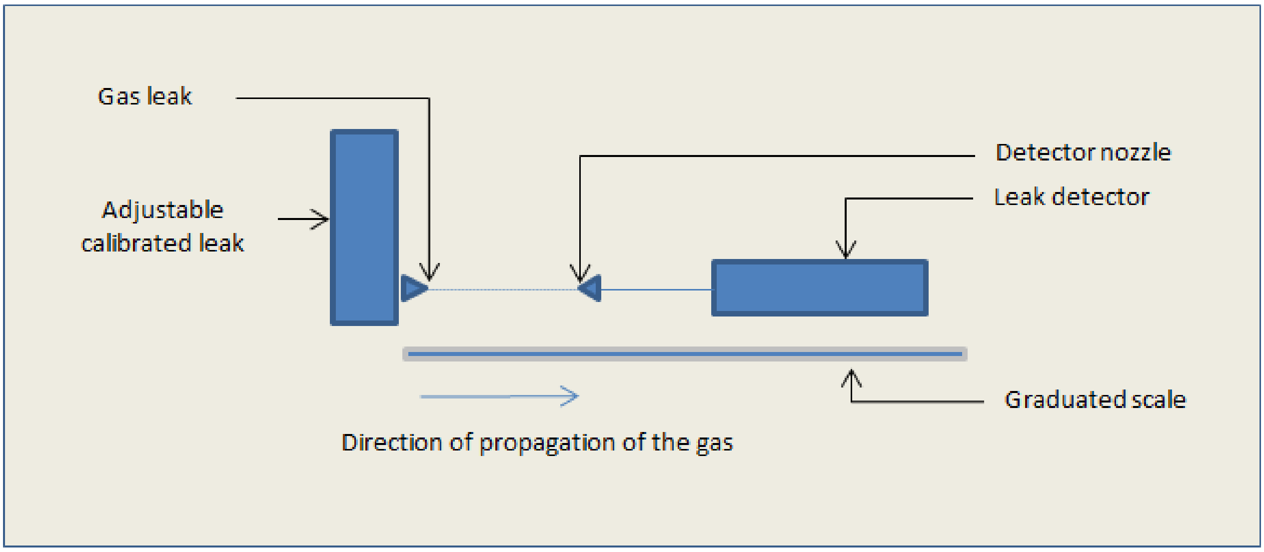


FIGURE 10. DIAGRAM OF THE TESTING DEVICE

4.2.4. Protocol

- Determine the detector reaction time:
  - Start the leak detector and wait until configuration is complete;
  - Set a determined flow of gas using the calibrated leak;
  - Position the detector facing the leak (less than 1 cm away);
  - Measure the response time.

- Determine how the detector/leak distance influences gas detection:
  - Start the leak detector and wait until configuration is complete;
  - Set a determined flow of gas using the calibrated leak;
  - Place the leak detector 10 cm away from the calibrated leak and bring it closer until gas is detected;
  - At this stage, note the distance from the leak detector to the calibrated leak.

4.2.5. Measurement Results

TABLE 8. DETERMINATION OF DETECTOR RESPONSE TIME

Leakage rate (g/yr.)	Response time	
	EQT-FRE-169	LG 11-030
4,5	Immediate	Immediate
7,9	Immediate	Immediate
13,7	Immediate	Immediate

TABLE 9. DETERMINATION OF HOW THE DETECTOR/CALIBRATED LEAK DISTANCE INFLUENCES GAS DETECTION

Leakage rate (g/yr.)	Minimum detection distance (mm)	
	EQT-FRE-169	LG 11-030
2,6	0	0
4,5	2	0
5,8	4	4
7,9	9	7
10,3	12	13
13,7	13	13

4.2.6. Development

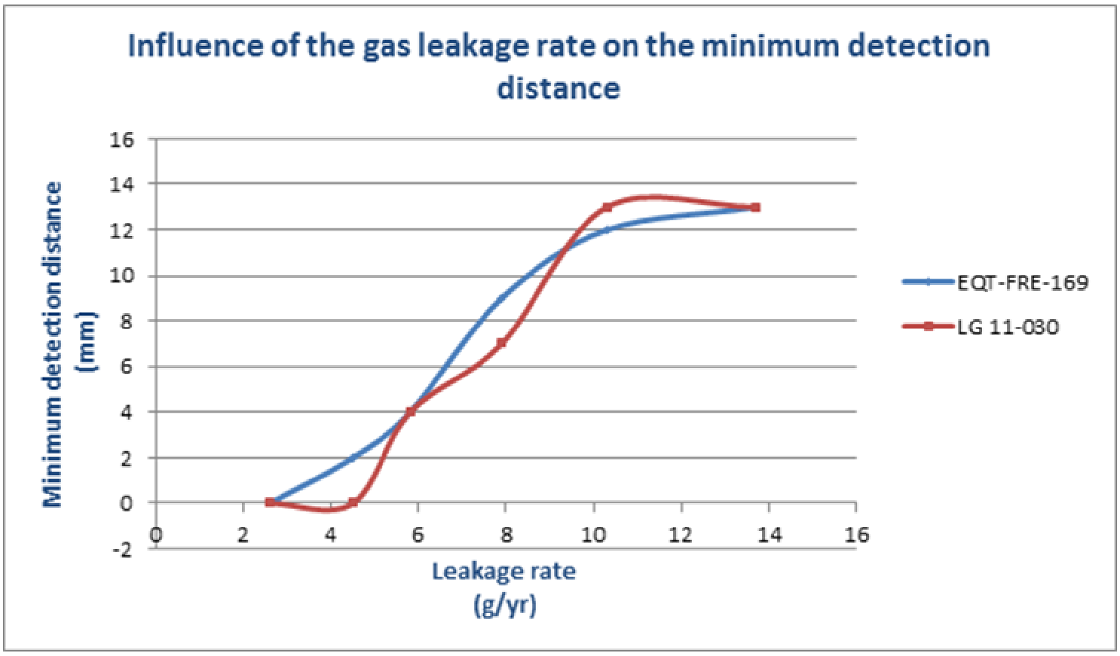


FIGURE 11. INFLUENCE OF THE GAS LEAKAGE RATE ON THE MINIMUM DETECTION DISTANCE

Facts to remember

During the study, laboratory testing helped determine how the method of use of leak detectors influences the performance of measuring instruments. Results show that the detectors' speed of travel has minor influence provided the operator remains within standard operating conditions (the leak detector must be in contact with the system under verification).

The minimum flowrate detected varies according to how the operator uses it. Thus, a leak detector calibrated to 5 g/yr.:

- *can detect leaks with a flowrate under 5g/yr;*
- *cannot detect a 5 g/yr. leak if it is positioned too far away from the source.*

It seems important that verification certificates of leak detectors specify the instruments' ideal distance of use for efficient detection of leaks 5 g/yr. and over.

4.3. Analysis of Recommended Detection Thresholds

4.3.1. Appraisal of Current Detection Methods

The vast majority of leak tests are performed with electronic leak detectors having a detection threshold in the range of 5 g/yr. This threshold is defined in the Order of 7 May 2007 regarding the leak testing of components ensuring the containment of refrigerants used in refrigerating and air-conditioning equipment.

One article [27] drew our attention to the importance of the sensitivity threshold of leak measuring apparatuses.

This document presents quantitative leak measurement methods, both in laboratories and on industrial sites. Various components were subjected to laboratory analysis, and 3,600 measuring points distributed across 15 sites were checked.

Onsite measurements were carried out with equipment capable of estimating the leakage level (multigas mass spectrometer with sniffer). The plants audited are those having components (flanges, valves, couplers, etc.) which may generate leakage. The selected sites are high capacity facilities using fluorinated refrigerants (food industry, refrigerated transport, industrial, air-conditioning, storage, ice-rink, etc...).

The results of this audit are given in the form of graphs, and show the leakage classes (in g/yr.) as a function of their frequency of occurrence.

No data is given regarding the (total) number of leakage points per plant.

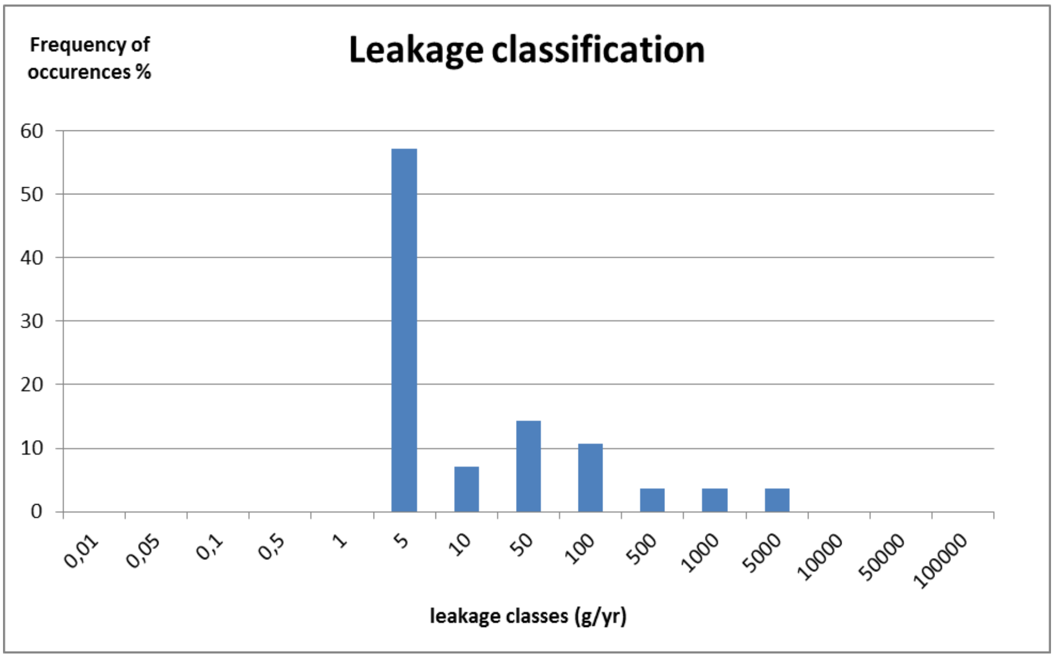


FIGURE 12: FREQUENCY OF OCCURRENCE OF LEAKAGE ACCORDING TO CLASS (G/YR.) WAREHOUSE (R22) TAKEN FROM REFERENCE [27]

From the data taken from the article, we were able to generate the following table on how a leakage class contributes to the total loss in refrigerant.

Frequency of occurrence (Fr in %)	Leakage Class (**Cl** in g/yr)	Class Contribution to total loss (**C_c** in %/ yr)	Potential loss of mass **m_p** (kg/yr) forr N = 100
0%	0,5	0,0000%	0,00
0%	1	0,0000%	0,00
57%	5	1,12%	0,29
7%	10	0,28%	0,07
14%	50	2,80%	0,72
11%	100	4,19%	1,07
4%	500	7,05%	1,8
4%	1000	14,09%	3,6
4%	5000	70,47%	18
0%	10000	0,00%	0,00
0%	50000	0,00%	0,00

Total mass **mtot**	26 kg/yr

TABLE 10: CALCULATION OF THE CONTRIBUTION OF A CLASS TO TOTAL LOSS, AND CALCULATION OF THE MASS POTENTIALLY LOST PER YEAR FOR A NUMBER OF LEAKS EQUAL TO 100

From this table it can be seen that leaks with the highest frequency of occurrence (57% of 5 g/yr. class leaks) represent only a very low relative contribution of 1.12% to the total mass of leakage (refrigerant potentially lost). This raises the question of whether a 5 g/yr. detection threshold is relevant for leak testing. Conversely, one can see that 91.6% of the leakage mass is due to classes over 500 g/yr.

From the operator's point of view, when performing leakage detection, chances are high that the operator will detect a large number of leaks having negligible impact. In the end, it is also possible that the operator will stop the analysis even before he has detected significant leakage, particularly on plants that are not easily accessible. It is important, therefore, to check for leaks thoroughly using several detection means. To qualify major leaks over 50g/yr., the soap bubble may prove to be the preferred method.

4.3.2. CO_2 statement for repair of a 5 g/yr. leak

In addition to this first approach analysis, it is of interest to incorporate the environmental impact (e.g., in terms of carbon footprint) of repairing a 5 g/yr. leak.

Let us take the case of servicing a valve which emits 5g/yr. of refrigerant, placed on a 100-litre liquid tank of a 70 kW refrigerating plant with T0= -30°C; TK = 35°C.

No consideration is given to:

- what is left in the hose;
- possible manipulation errors;
- refrigerant present in the oil (possibly 10% or more of the oil mass).

If we consider a leak with a rate of T_x=5 g/yr. for N=15 years for a plant containing R404A (GWP: 3900), this amounts to: N x T_x x GWP= 292 kg_{eq} CO_2

Let us now take the case where this 5 g/yr. leak will be repaired. The first objective will be to recover the plant refrigerant prior to repairing the component causing the leak.

If we consider that in this operation, the recovery unit stops when relative pressure is 0.2 bar, the volume of the facility being V=100 litres at a temperature of 20°C, density V''= 0.31 m^3/Kg.

The resulting residual mass of refrigerant in the plant m=V/V''=326g.

This residual mass will inevitably be released to the atmosphere during the repair and its impact will therefore be 1262 kg_{eq} CO_2.

This calculation shows that repairing a single 5 g/yr. leak may be much more harmful to the environment than leaving it as is for 15 years.

This budget demonstrates the value of shut-off valves which can avoid draining the entire plant to perform the repair, by shutting off only the portion of the system which is to be repaired.

When there is no shut-off valve, one should avoid frequently draining the plant to repair low rate leakages, or wait until the next preventive maintenance operation to perform the repair.

Facts to remember

The authors of this report wish to draw the reader's attention to the technical relevance of the current detection threshold level. To be effective when testing for leakage, it would be best to focus mainly on major leaks. Detectors having numerous detection thresholds could be a significant step forward in this area.

Leakage detection has to be carried out exhaustively on the entire installation.

5. Result on the Online Survey

5.1. Introduction

The online survey was sent to more than 500 French installers/maintainers of refrigerating equipment holding a qualification certificate. Roughly forty completed questionnaires were returned to us, which amounts to an 8% response rate. This rate is consistent with the results of a similar study conducted in the UK (see Datasheet 7). This relatively low participation rate can be explained by the fact that the containment of facilities remains a sensitive issue for both the refrigeration specialists and the facility owners, although the authors of the study established strict confidentiality agreements regarding the data supplied. In addition, the professionals who were contacted mentioned a lack of resources to complete the survey.

The results of the survey in terms of leakage rates are in line with the relevant literature. Drafting conclusions on non-accident related leakage rates was difficult because the refrigerant refills, as recorded on the job sheets, essentially relate to serious failures having caused very severe leakage.

5.2. Nature of the plants

Among the 40 questionnaires returned, 40% pertained to air-conditioning systems and urban refrigeration networks, 25% to refrigerated warehouses, 20% to facilities for large and medium-size retail, 10% to the food industry and 5% to refrigerating units for transport.

Xx

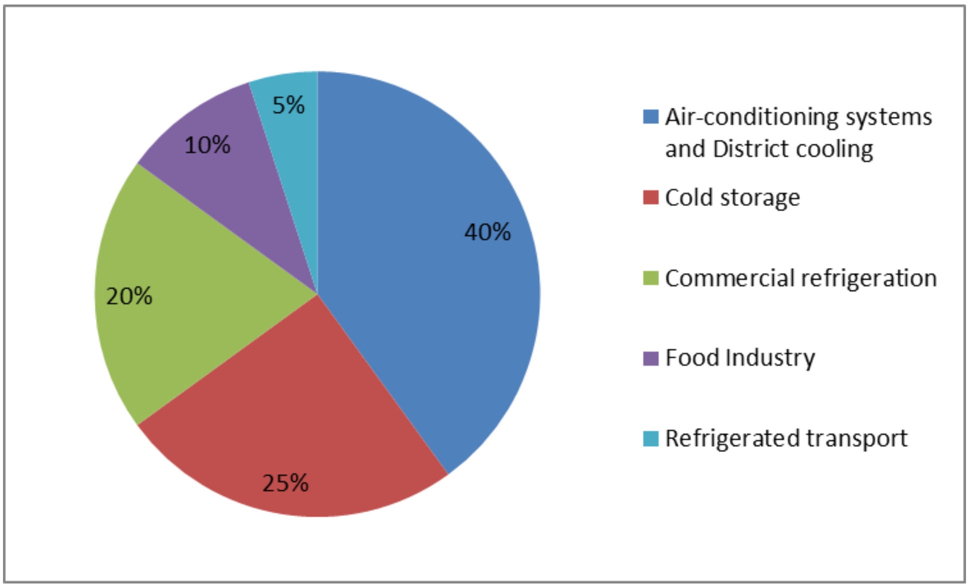


FIGURE 13. NATURE OF THE FACILITIES ANALYSED IN THE PANEL

Most of the time, the questionnaires were accompanied by on-site job sheets. A wide disparity was observed in the quality of the information provided in these sheets. The refrigerant charge is not always mentioned on the job sheet. The charge may vary by 50% from one job to another.

5.3. Data Collection

5.3.1. Air-conditioning

Pressure tapping connections are frequently incriminated, as are compressor shaft seal fittings.

5.3.2. Refrigerated warehouses

Pressure tapping connections are regularly mentioned in the survey responses.

5.3.3. Commercial refrigeration

In commercial refrigeration, the main causes of leakage relate to terminals (cold room evaporators, evaporators for refrigerated display cabinets, equipment connected with positive and negative loops). On the positive loop, the evaporators (copper-made) of the proofing cabinets (chamber for storage of dough pieces for bakery products) are often porous. On the negative loop, ice machines (for seafood display) are often incriminated.

5.3.4. Agrifood Industry

In the handful of questionnaires on agrifood industries, major leaks relate to pressure tapping connections, to liquid line, evaporators of ventilated cold rooms, and discharge slotted tube.

5.3.5. Refrigerated Transport

For refrigerated transport, the occurrences and the sources of leakage strongly depend on the technology used. Driven-belt units are much more susceptible to leakage than independent units. The reason is that mechanical loads are much heavier.

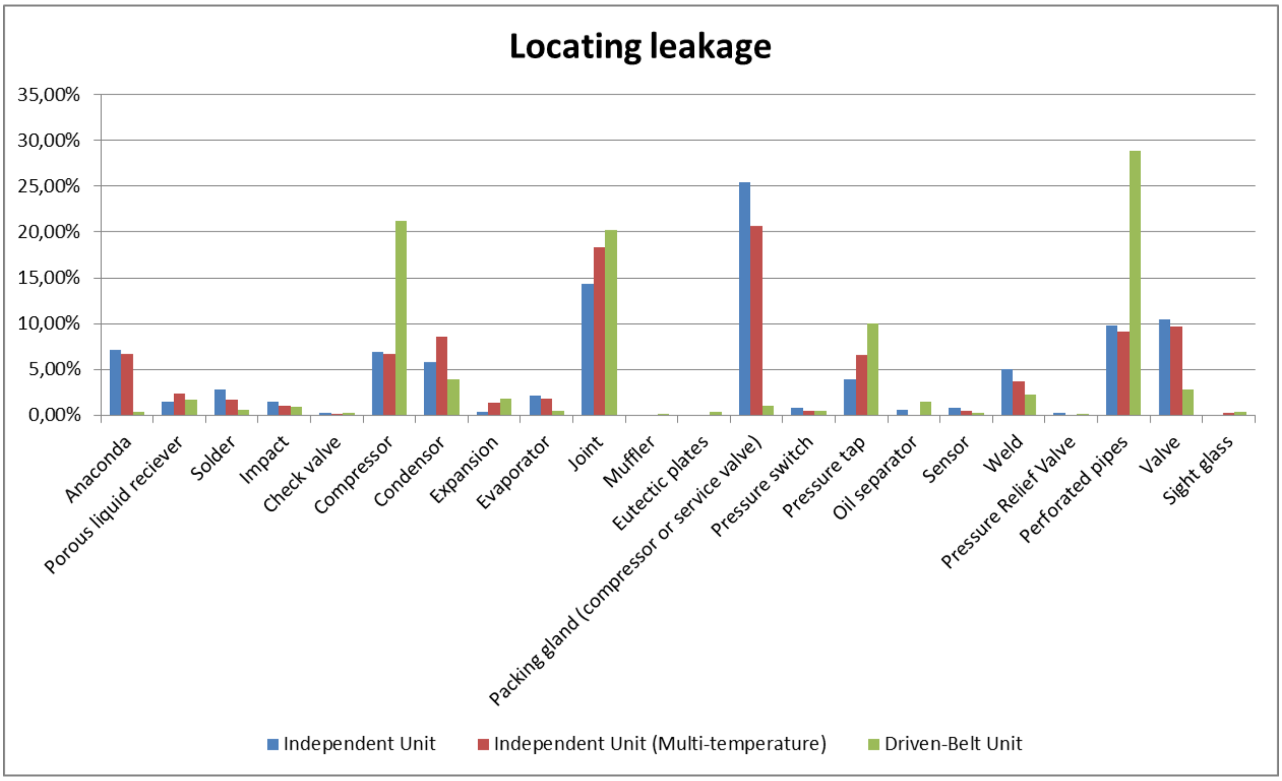


FIGURE 14. LOCATING LEAKAGE IN TRANSPORT REFRIGERATION UNITS

For driven-belt units, 70% of the leaks observed are located on the pipework, at the compressor, at pressure taps or on seals. To a lesser extent, leaks are found at the valves, the condenser, the expansion valve or the liquid receiver.

For independent units, whether single- or multi-temperature, 50% of the leaks are located at seal fitting (compressors or service valves), seals and anacondas. Welds and solders are incriminated only in 5% of the cases.

Facts to remember

For the study, an online survey was sent to more than 500 French installers/maintainers of refrigerating equipment holding a qualification certificate. The response rate was 8% which is a satisfactory result in view of the response rates of earlier studies. Generally, the causes of leakage found are the same as those found in the literature, with marked differences according to the line of activity and the technology used.

The quality of job sheets and leak test reports is very irregular. It would seem relevant to develop a leakage detection procedure or method which uses several types of detection systems and a number of compulsory check points.

In addition, given the wide range of applications and refrigeration systems, the detection method should vary according to the types of facilities.

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6. On-site Assessment of equipment or facility

6.1. Introduction

Visits were conducted by Cemafroid experts, the facilities being visited on the basis of the previously completed questionnaires. About twenty visits were conducted in all areas of refrigeration:

- Air-conditioning systems;
- Refrigerated warehouses;
- Refrigerating plants in large and medium-size retail stores;
- District Cooling;
- Food industry.

During these visits the technical documentation of the facility was examined, as well as the job sheets. Where possible, the experts examined the maintenance contract to check the frequency and the periodic checkpoints performed.

The experts analysed the facilities by answering the analysis grid provided in Appendix 2. The completed sheets are given in Appendix 4.

6.1.1. District Cooling / Air conditioning system

In general, refrigerating plant which have been visited were well-maintained (Sheets n°1, 4, 6 and 18 in Appendix 4). For this kind of large facilities, maintenance operations, including leak tests, were performed internally, with frequency well beyond the regulations requirements. Leak detection methods look like not well adapted for large refrigerating plant and should be revised. Even if refrigerant recovery operations were performed correctly, in some cases, still a large amount of refrigerant stays dissolved in oil. Operation sheets could be completed in more valuable way.

6.1.2. Warehouses

Visited facilities (Sheets n ° 3, 9, 10, 11 and 14 of annex 4) were relatively new for most of them with massive recourse to hoses which accentuate the risk of leak if they are not changed periodically. Despite a customer high level of satisfaction and a maintenance contract planning many controls and preventive maintenance, a R404A installation was in advanced dilapidation status (missing cap, advanced corrosion and presence of mud to the right of the compressors).

6.1.3. Commercial refrigeration, supermarkets and hypermarkets

Visited facilities (Sheets n ° 5, 8, 12, 13, 16 and 17 of Schedule 4) are a massive recourse to hoses which accentuates the risk of leak if they are not changed periodically. In addition, facilities are characterized almost systematically by a massive number of Schrader valve and missing plugs.

6.1.4. Agrofood industry

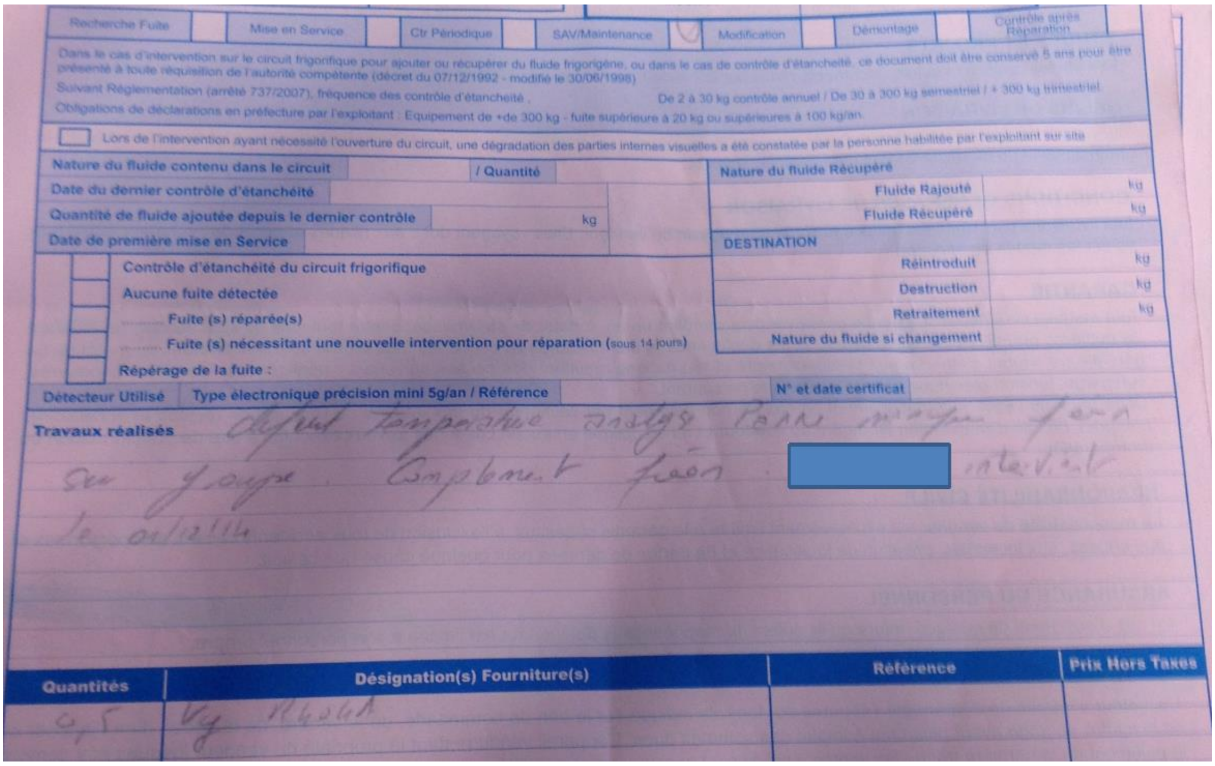
The visited facilities (Sheets n ° 2, 7 and 15 of Schedule 4) are all relatively old with much corroded components. Installations are generally well maintained.

6.2. Feedback

In general, there are major differences of approach in maintenance contracts. Most of the refrigerated warehouses and urban refrigerating plants visited maintained their facilities particularly well, but maintenance contracts for air-conditioning systems, large and medium-size retail facilities on the other hand, included little or no preventive maintenance or replacement of worn parts.

In all areas, the experts made comments on the quality of the information found in the job sheets. The causes of leakage are not always explained. Some of the leaks found are not repaired prior to recharging.

The equipment used for leak testing is not specified: brand, part number, date last verified.



Recherche Fuite | Mise en Service | Ctr Périodique | SAV/Maintenance | Modification | Démontage | Contrôle après Réparation

Dans le cas d'intervention sur le circuit frigorifique pour ajouter ou récupérer du fluide frigorigène, ou dans le cas de contrôle d'étanchéité, ce document doit être conservé 5 ans pour être présenté à toute réquisition de l'autorité compétente (décret du 07/12/1992 - modifié le 30/06/1998)
Suivant Réglementation (arrêté 737/2007), fréquence des contrôle d'étanchéité , De 2 à 30 kg contrôle annuel / De 30 à 300 kg semestriel / + 300 kg trimestriel
Obligations de déclarations en préfecture par l'exploitant : Equipement de +de 300 kg - fuite supérieure à 20 kg ou supérieures à 100 kg/an

Lors de l'intervention ayant nécessité l'ouverture du circuit, une dégradation des parties internes visuelles a été constatée par la personne habilitée par l'exploitant sur site

Nature du fluide contenu dans le circuit / Quantité
Date du dernier contrôle d'étanchéité
Quantité de fluide ajoutée depuis le dernier contrôle kg
Date de première mise en Service

Nature du fluide Récupéré
Fluide Rajouté kg
Fluide Récupéré kg
DESTINATION
Réintroduit kg
Destruction kg
Retraitement kg
Nature du fluide si changement

Contrôle d'étanchéité du circuit frigorifique
Aucune fuite détectée
.... Fuite (s) réparée(s)
.... Fuite (s) nécessitant une nouvelle intervention pour réparation (sous 14 jours)
Repérage de la fuite :

Détecteur Utilisé | Type électronique précision mini 5g/an / Référence | N° et date certificat

Travaux réalisés [redacted]

Quantités	Désignation(s) Fourniture(s)	Référence	Prix Hors Taxes
0,5	R404A		

FIGURE 15. EXAMPLE OF AN INCORRECTLY COMPLETED JOB SHEET
(SYSTEM RECHARGED WITH R404A WITHOUT PRIOR REPAIR).

Where refrigerating plants are concerned, the number of pressure tapping connections is sometimes far too high, increasing the risk of leakage.

FIGURE 16: EXAMPLE OF A COMPRESSION PLANT FEATURING NUMEROUS PRESSURE TAPS

Some facilities located outdoors were particularly corroded, especially e.g. at suction receiver or pressure switch connections.

Most of the facilities visited did not comply with the requirement on pressure equipment follow-up in service (amended order of 15 March 2000 and CTP of 7 July 2014).

FIGURE 17: EXAMPLE OF ADVANCED CORROSION ON OUTDOOR SUCTION RECEIVER

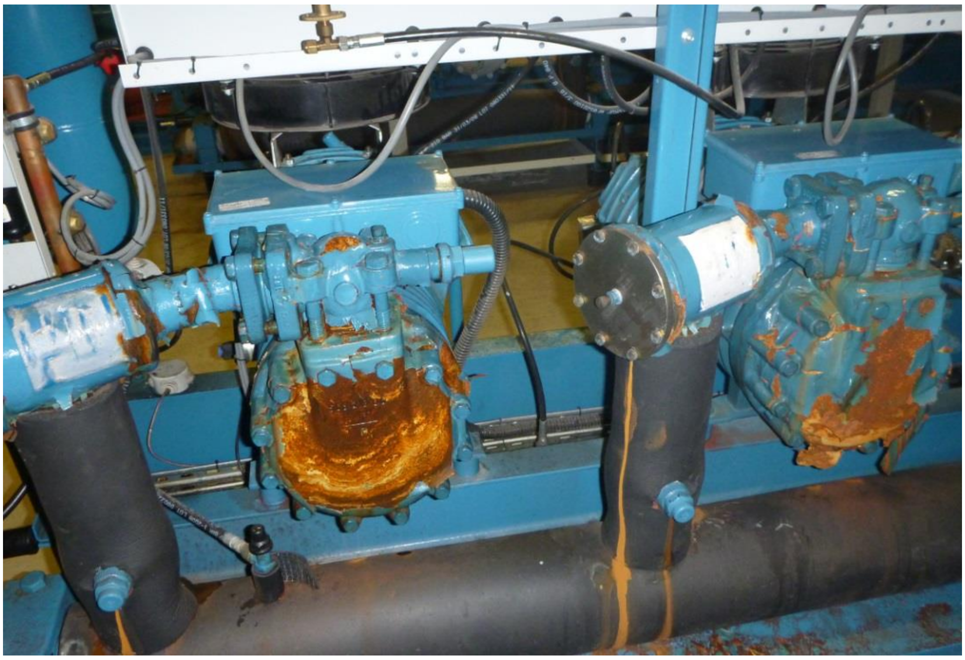


FIGURE 18. EXAMPLE OF A HIGHLY CORRODED COMPRESSOR FLANGE

FIGURE 19. PRESENCE OF OIL ON THE GROUND

FIGURE 20. PRESSURE SWITCH WITH NO PROTECTIVE BOX, PRESSURE SWITCH BELLOWS IN BAD CONDITION

Some facilities included anti-vibration pads beneath the plant but the system did not have an anti-vibration hanger or vibration absorber.

For some recent facilities, welds were poorly performed with too many hoses present, increasing the risk of leakage when they are not changed regularly:

FIGURE 21. EXAMPLE OF A POORLY PERFORMED WELD

FIGURE 22. SYSTEMATIC PRESENCE OF HOSES

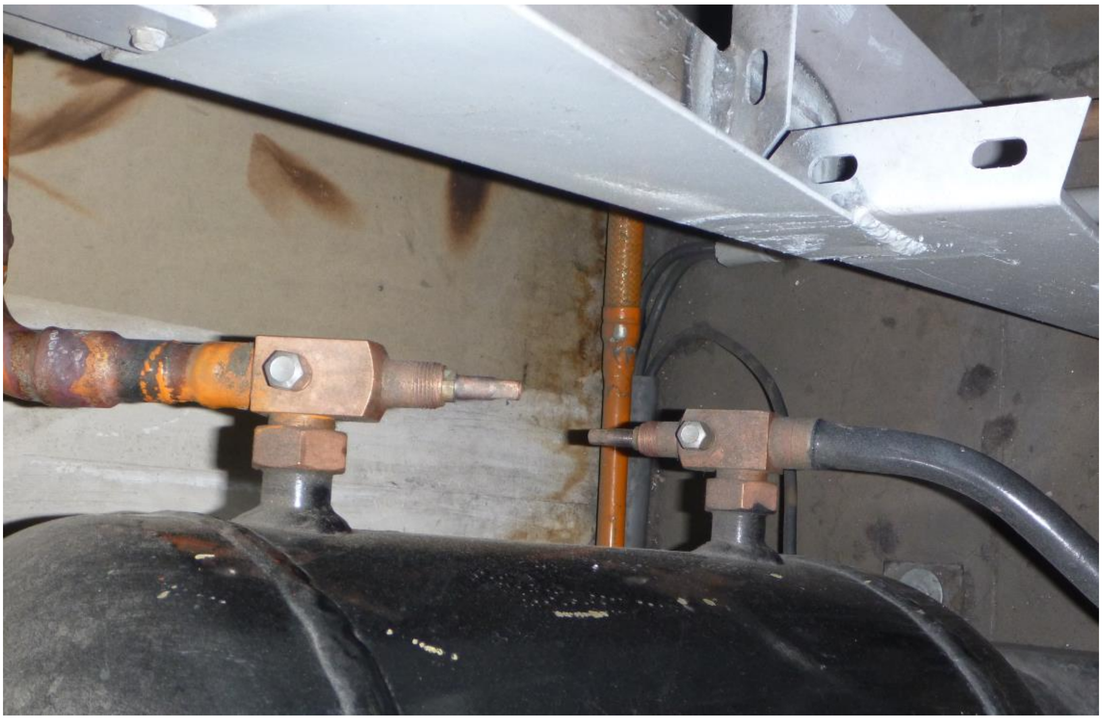


FIGURE 23. NO PLUG ON VALVE

The experts also observed some excellent practices in major District cooling refrigerating plants, including the caulking of leakage-susceptible components to better detect possible leaks.

FIGURE 24 EXAMPLE OF CAULKING A FLANGE FOR MORE EFFICIENT LEAK DETECTION

Pressure relief valves were connected with a storage tank which was coupled to a transfer station designed in-house. This equipment was not EN 35421 compliant, but it was much more effective than a compliant station. The station was equipped with a vacuum pump system which enabled the recovery of any residual vapour in the plant to be recovered in a storage tank.

For some facilities with very high cooling capacity, the operation sheets were well completed, with leak tests referring to calibrated leak testing equipment:

Commande : CF130283 du 13/08/2013

CERTIFICAT D'ETALONNAGE

N° 13-845-T296 R01

Délivré à :

INSTRUMENT ETALONNE

Désignation : CHAINE DE MESURE DE TEMPERATURE

Constructeur : FLUKE

Type : 1523 N° de série : 9794039
Identification : /

Ce certificat comprend 4 pages Date d'émission : 26 septembre 2013

LE RESPONSABLE DU LABORATOIRE

Carole BEAULIEU
Tristan BESSIERE, suppléant

FIGURE 25. SAMPLE CALIBRATION CERTIFICATE

Facts to remember

During the study, about twenty site visits were completed on facilities in all areas of refrigeration. There are wide disparities in terms of maintenance according to the area under consideration. Regardless of the area, experts commented on the quality of the information found in the job sheets. The causes of leakage are not always explained. Some of the leaks noted are not repaired prior to recharging, which is strictly forbidden.

The majority of the facilities visited were not compliant with the Pressure Equipment Directive regarding the in-service equipments follow up, and showed advanced corrosion. The compliant facilities, which were periodically inspected, were much better maintained.

7. Recommendations

Containment recommendations are aimed at raising awareness among:

- Engineering departments who designed the plant;
- Installers;
- Operators;
- Maintainers;
- Public Authorities.

The authors also present the recommendations in the form of sectoral sheets given in Appendix 5

7.1. Engineering Departments

Engineering departments play a very important role because the choice of the equipment and the layout of the facility will have a strong impact on the correct containment of the facility throughout its life.

7.1.1. Refrigerant Charging

Designers should minimise refrigerant charging where possible. Dry expansion systems should be limited to selected types of equipment for which no other alternative exists (VRF, Multisplit system). It is preferable to opt for a coolant system so as to minimise charging. Microchannel heat exchangers, which are widely used in the automotive sector, can help significantly reduce charging (up to 75% according to certain manufacturers).

7.1.2. Network and Equipment Accessibility

Designers should facilitate maintenance by providing access to the entire plant, including distribution networks. In the area of commercial refrigeration, trenches and underground networks should be avoided.

7.1.3. Vibration

Vibration is a major source of fatigue on piping systems and is the cause of many leaks.

7.1.4. Connections/Valves

As repeatedly mentioned in this report, it is important to reduce the number of welded or soldered connections and prohibit the use of Schrader connections. All valves must be capped.

To facilitate maintenance, it is advisable to fit system shut-off valves and by-passes on wear parts or frequently replaced equipment.

7.1.5. Tank Sizing

It is important for tanks to be properly sized to receive the entire system charge while minimising the refrigerant mass in the facility.

7.2. Installation

7.2.1. Personnel

Assembly personnel must be qualified and welders have proper authorisation, which means that they should at least hold a certificate of capability.

Vocational training is a key issue for the refrigeration technician, since he/she is expected to acquire additional skills especially on natural refrigerant or risk-bearing technologies (equipment of category 1 to 4 according to the PED).

7.2.2. Sensitive Procedures

A number of procedures can help avoid leakage and should be taken into account by the installer when performing the assembly:

- Protect the soldered member with a damp cloth to prevent damage to the seal;
- Tighten to the torque prescribed by the manufacturer;
- For flares, use an eccentric flaring tool;
- Tighten flanges to the specified torque applying the cross-pattern rule in 3 gradual passes;
- Ensure the pressure switch is properly fixed and supported.

On commissioning, the installer should:

- Leak test the entire plant. All connections should be checked using a spray or ultrasonic detector;
- Explain the role of maintenance. Thus the operator should adopt a consulting approach with respect to the owner in regard to his responsibilities.

7.2.3. Detection Equipment

Leak detectors must be installed in the machinery room. To place the atmosphere detector sensors in the best position, it is advisable to:

- Perform a general diagnostic of the plant's condition in terms of leakage;
- List the most sensitive components (e.g., valves, unloading valve etc.);
- Position the sensors as close as possible to those components;
- Take particular care in determining the required height of the sensor according to the type of gas it will detect (whether the refrigerant is heavier or lighter than air).

Where possible use indirect leakage detection with alarm transfer.

7.3. Operation (equipment owner)

The comments hereafter are intended for owners of refrigerating equipment. Keep in mind that F-Gas establishes the owner as responsible for the proper containment of his refrigerating plant. Operators are required to properly maintain their facilities. In general, few operators are familiar with their refrigerating plant and too often rely on their maintenance providers. It seems important that the operator, in the same way as he monitors his energy use, be capable of monitoring his leakage rate.

7.3.1. Plant Design

The operator should accept the adjustments and the design layout proposed by the engineering department, aiming to minimise leakage and facilitate detection and repair (see Engineering Department Paragraph).

7.3.2. Compliance with Current Regulations

The operator must comply with the Environmental Code by properly maintaining the job logbook, by visually inspecting the plant. He must also abide by the amended Order of 15 March 2000 relating to operation of pressure equipment and implement the Professional Technical Handbook (*Cahier Technique Professionnel*) for in-service monitoring of pressurized refrigeration systems of 7 July 2014. In fact, a number of facilities still do not comply with the pressure equipment Directive. Technical files are incomplete, the initial visit and periodic inspections have not been performed.

7.3.3. Maintenance

The plant operator should give preference to “long term” service contracts, enabling any action implemented in leakage reduction to be written off over time and ensuring intelligent management of the facility. The maintainer will have better knowledge of the facility, more control over his service jobs and will be more likely to improve the containment of a facility, if he is certain that his contract is a long-standing one.

It is also in the interest of the Operator to properly maintain his facility by following the operating instructions from the manufacturers and accepting the repairs and adjustments proposed by the maintainer if necessary. These repairs should not be performed precipitously, without a leak test being conducted when the work is done.

During compulsory leak tests, it is the Operator’s responsibility to provide free access to the whole plant and to allow the maintainer enough time to conduct the test effectively and completely.

7.4. Maintenance (maintenance manager)

7.4.1. Compliance with Current Regulations

The maintainer must comply with the Environmental Code by properly maintaining the job logbook, the reporting forms, and by visually inspecting the plant. He must also abide by the Order of 15 March 2000 (amended 31 January 2011) relating to operation of in-service pressure equipment.

7.4.2. Plant Monitoring

It is important to perform preventive maintenance and performance control, and to submit a report to the equipment owner, being vigilant into the installation monitoring (for vibration, caps and seals improperly tightened or missing, etc.) and performing inspections (pre- and post-leakage).

Knowing how to detect, perform or suggest preventive maintenance actions on sensitive parts and immediately correct any corrosion point is a key element.

Leakage on connections often appears following a maintenance procedure; therefore, it is essential to conduct the leak test using an electronic detector before leaving the facility.

7.4.3. Establishing a relationship of trust with the operator

To establish a relationship of trust means above all to build a healthy, win-win type relationship. The maintainer should always suggest to his client that an annual contract review be conducted during which the following will be examined:

- services calls performed;
- contractual visits performed;
- quotes drawn up;
- quotes awaiting validation by the operator;

- refrigerant consumption;
- 24/24 service jobs;
- Operator’s expectations and issues for the coming months;
- potential usage problems;
- energy consumption;
- Regulatory watch.

This contract review is an opportunity to assess the leakage rate of the facility and, together with the client, to validate solutions to minimise it.

7.4.4. Leak Test

To conduct a quality leak test, the maintainer should follow a number of rules:

- Allow enough time to conduct the test and have it planned in the contract;
- Test the electronic detector with a calibrated leak prior to conducting the test;
- Search for leaks methodically as recommended by F-Gas;
- Check all connections using a spray or ultrasonic detector;
- Always leak test inside the pressure switch, keeping in mind the risk of electric shock;
- Leak test return bends carefully, especially if the atmosphere is aggressive;
- Always leak test safety pressure valves and fusible plugs;
- Test for leakage as soon as an oil trace appears
- If leakage is confirmed, repair as soon as possible and recheck the system at the repair point within a month
- Have the facility tested by qualified personnel. Leak testing pressure should be maintained at least 24 hours for commissioning, and 1 hour when replacing a part (a small portion of a system);
- Use tracer gas (helium or hydrogen) with the appropriate associated detector (your HCFC/HFC detector will not work for this type of gas);
- Wipe off traces of fluorescent product used to detect leakage;
- Keep in mind that the first leak found may not be the last.

7.5. Public Authorities

The following comments are intended for ministries, associations, public institutions, European committees.

7.5.1. Relying on the studies carried out

There are a number of studies on the issue of containment. In addition to this report, Public Authorities should make use of the studies carried out by ADEME, AFCE, Armines, Cetim, Cemafroid, IRSTEA, Perifem, and UNICLIMA.

According to these studies there are significant differences in containment, depending on the technologies employed and the line of activity.

This study raises the technical relevance of substantially increasing the detection thresholds of the detectors to make leak testing more effective.

Furthermore, because of the more stringent regulations on fluorinated refrigerants and the implementation of some degree of traceability in refrigerant flows, refrigerant handling organisations are required to be aware of the flows for which they are responsible, but this traceability is only relative when it comes to the operator or the equipment. The authors of this report wish to draw the Public Authorities attention to the importance of setting up flow traceability at operator or refrigerating plant level.

7.5.2. Regulatory and Normative Context

PED 2014/68/EU, the Pressure Equipment Directive, introduces requirements on the manufacture of refrigerating plants or refrigerating equipment which make up assemblies used in refrigeration and air-conditioning. These requirements on the safety of pressure devices help improve containment.

The EN 378 standard on refrigeration systems and heat pumps, and the EN 13480-5 standard on inspection and testing of industrial piping are harmonised with the PED and provide selection criteria for the design and operation of refrigerating plants which help minimise refrigerant leaking through regular testing and inspection of the system.

Public Authorities can rely on the existing regulatory texts which support proper containment of facilities.

The authors of this report wish to draw the Public Authorities' attention to the importance of establishing standard rules for detection methods in order to ensure comprehensiveness of the leak testing process.

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9. List of Tables

10. List of Figures

Appendices

Appendix 1: Online Survey Template

cemafroid
L'EXPERT DU FROID

Enquête : Confinement des installations

Le Cemafroid et IRSTEA réalisent une étude sur le confinement des installations frigorifiques

L'AFCE (Alliance Froid Climatisation Environnement) et l'ADEME lancent une étude sur le confinement des installations frigorifiques. L'objectif affiché est de fournir une typologie des origines des fuites dans les installations et en déduire des préconisations pour les limiter. Le nouveau règlement européen F-Gaz renforce en effet les prérogatives du précédent règlement concernant l'incitation au confinement des fluides frigorigènes dans les circuits, l'obligation du contrôle régulier d'étanchéité et de l'installation de détecteurs de fuites dans les installations de plus de 500 t.éq. CO_2 de gaz fluorés, notamment.

Afin de compléter ce questionnaire, nous vous conseillons de vous munir préalablement du registre de l'installation ou des fiches d'intervention précisant les charges en fluides frigorigènes et les opérations de maintenance effectuées.

Aucun champ technique n'est obligatoire, cependant pour la qualité de notre étude, nous vous remercions de vous efforcer à compléter le plus précisément possible chacun des champs et de fournir, à minima, les fiches d'intervention sur l'installation.

La confidentialité des échanges sera assurée par les consultants et aucune donnée chiffrée sur l'installation elle-même ne sera publiée.

Les participants à l'enquête disposeront d'informations pour comparer le niveau de confinement global de leur installation au confinement moyen du secteur d'activité considéré.

La durée de saisie est estimée à 15 minutes.

Le rapport final, présentant notamment les données qualitatives sur les origines des fuites et des préconisations, sera rendu public via internet sur le site du commanditaire de l'étude (www.afce.asso.fr).

Pour toute question ou difficulté lors de la saisie, n'hésitez pas à contacter Thomas Michineau, le pilote de l'étude, au 01 49 84 84 84 ou par mail à thomas.michineau@cemafroid.fr.

L'enquête est ouverte jusqu'à fin février 2015. Une fois complété, merci de renvoyer par mail le document scanné à l'adresse suivante : thomas.michineau@cemafroid.fr

Cemafroid SAS - 5 avenue des Prés - CS 20029 - 94266 FRESNES Cedex - Tél. +33 1 49 84 84 84 - Fax +33 1 46 89 28 79 - www.cemafroid.fr
Siège social: 5-13 avenue des Prés - 94260 FRESNES
Société par Actions Simplifiée au Capital de 893 189 euros - RCS Créteil 432 511 897 - APE 8299Z - TVA FR 71 432 511 897

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Enquête : Confinement des installations

Participant au panel de l'étude

NOM :

Prénom :

Entreprise :

Fonction :

E-mail :

Tél :

Information générale sur l'installation

Application concernée :

Cocher la case correspondante

Agroalimentaire		Froid commercial	
Climatisation fixe		Pompe à chaleur	
Climatisation mobile		Procédé industriel	
Entreposage		Transport frigorifique	

Adresse de l'installation :

Adresse :

Code Postal :

Ville :

Responsable technique de l'exploitant de l'installation :

NOM :

Prénom :

Entreprise :

Fonction :

E-mail :

Tél :

Date de mise en service : __/__/__

Type d'architecture de l'installation :

Décrire l'installation, exemple : centrale de production d'eau glacée

Marque/Assembleur

Mentionner la marque pour un équipement ou les coordonnées de l'installateur pour une installation assemblée sur site.

Cemafroid SAS - 5 avenue des Prés - CS 20029 - 94266 FRESNES Cedex - Tél. +33 1 49 84 84 84 - Fax +33 1 46 89 28 79 - www.cemafroid.fr
Siège social: 5-13 avenue des Prés - 94260 FRESNES
Société par Actions Simplifiée au Capital de 893 189 euros - RCS Créteil 432 511 897 - APE 8299Z - TVA FR 71 432 511 897

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Enquête : Confinement des installations

Fiches d'intervention sur l'installation au cours des 2 dernières années

Merci de bien vouloir nous envoyer un scan de l'ensemble des fiches d'intervention référencées ci-dessous.

Intervention 1

Date :

Societe :

Quantite de fluide chargee (en kg) :

Quantite de fluide recuperee (en kg) :

Organe ou composant éventuellement réparé :

Nature de l'intervention (Cocher la case correspondante) :

Entretien periodique		Panne	
Controle d'etancheite		Retrofit	
Recherche de fuite localisee		Modification de l'installation	
Autre : (préciser)			

Intervention 2

Date :

Societe :

Quantite de fluide chargee (en kg) :

Quantite de fluide recuperee (en kg) :

Organe ou composant éventuellement réparé :

Nature de l'intervention (Cocher la case correspondante) :

Entretien periodique		Panne	
Controle d'etancheite		Retrofit	
Recherche de fuite localisee		Modification de l'installation	
Autre : (préciser)			

Intervention 3

Date :

Societe :

Quantite de fluide chargee (en kg) :

Quantite de fluide recuperee (en kg) :

Organe ou composant éventuellement réparé :

Nature de l'intervention (Cocher la case correspondante) :

Entretien periodique		Panne	
Controle d'etancheite		Retrofit	
Recherche de fuite localisee		Modification de l'installation	
Autre : (préciser)			

Intervention 4

Date :

Societe :

Quantite de fluide chargee (en kg) :

Quantite de fluide recuperee (en kg) :

Organe ou composant eventuellement repare :

Nature de l'intervention (Cocher la case correspondante) :

Entretien periodique		Panne	
Controle d'etancheite		Retrofit	
Recherche de fuite localisee		Modification de l'installation	
Autre : (préciser)			

Intervention 5

Date :

Societe :

Quantite de fluide chargee (en kg) :

Quantite de fluide recuperee (en kg) :

Organe ou composant éventuellement réparé :

Nature de l'intervention (Cocher la case correspondante) :

Entretien periodique		Panne	
Controle d'etancheite		Retrofit	
Recherche de fuite localisee		Modification de l'installation	
Autre : (préciser)			

ADEME
Agence de l'Environnement et de la Maîtrise de l'Energie

Enquête : Confinement des installations

Intervention 6

Date : Société :

Quantité de fluide chargée (en kg) : Quantité de fluide récupérée (en kg) :

Organe ou composant éventuellement réparé :

Nature de l'intervention (Cocher la case correspondante) :

Entretien périodique		Panne	
Contrôle d'étanchéité		Retrofit	
Recherche de fuite localisée		Modification de l'installation	
Autre : (préciser)			

Intervention 7

Date : Société :

Quantité de fluide chargée (en kg) : Quantité de fluide récupérée (en kg) :

Organe ou composant éventuellement réparé :

Nature de l'intervention (Cocher la case correspondante) :

Entretien périodique		Panne	
Contrôle d'étanchéité		Retrofit	
Recherche de fuite localisée		Modification de l'installation	
Autre : (préciser)			

Intervention 8

Date : Société :

Quantité de fluide chargée (en kg) : Quantité de fluide récupérée (en kg) :

Organe ou composant éventuellement réparé :

Nature de l'intervention (Cocher la case correspondante) :

Entretien périodique		Panne	
Contrôle d'étanchéité		Retrofit	
Recherche de fuite localisée		Modification de l'installation	
Autre : (préciser)			

Intervention 9

Date : Société :

Quantité de fluide chargée (en kg) : Quantité de fluide récupérée (en kg) :

Organe ou composant éventuellement réparé :

Nature de l'intervention (Cocher la case correspondante) :

Entretien périodique		Panne	
Contrôle d'étanchéité		Retrofit	
Recherche de fuite localisée		Modification de l'installation	
Autre : (préciser)			

Intervention 10

Date : Société :

Quantité de fluide chargée (en kg) : Quantité de fluide récupérée (en kg) :

Organe ou composant éventuellement réparé :

Nature de l'intervention (Cocher la case correspondante) :

Entretien périodique		Panne	
Contrôle d'étanchéité		Retrofit	
Recherche de fuite localisée		Modification de l'installation	
Autre : (préciser)			

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Enquête : Confinement des installations

Information complémentaires

Fluides utilisés

Nature du fluide frigorigène

Utiliser la nomenclature normalisée (R134a, R404A, R717, R744, ...)

Quantité de fluide frigorigène

Mentionner la quantité nominale (en Kg de fluide) présente sur la plaque de l'équipement

Compresseur

Puissance frigorifique totale de l'installation

En kW

Nombre de compresseurs

Mentionner la quantité nominale (en Kg) présente sur la plaque de l'équipement

Type de compresseurs

Cocher la case correspondante

Piston		Scroll	
Centrifuge		Rotatif	
Vis			

Le compresseur est-il ?

Cocher la case correspondante

Ouvert		Semi-hermetique	
Hermetique			

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ADEME
Agence de l'Environnement et de la Maîtrise de l'Energie

Enquête : Confinement des installations

Circuit frigorifique

Vos tuyauteries sont-elles protégées mécaniquement contre les chocs liés à l'activité concernée (protection contre les chocs d'un engin de manutention dans un entrepôt, protection du bâti pour un rooftop, ...)

Cocher la case correspondante

Non concerné		Conception empêchant les chocs (réseau enterré)	
Protection par capotage, grille		Conception empêchant les chocs (en hauteur)	
Mise en place d'une signalétique		Circuit non protégé	

Votre équipement/installation dispose-t-il de dispositifs anti vibratiles?

Si vous répondez par l'affirmative veuillez préciser le type de dispositif et sa localisation : silent block, anaconda, suspente anti-vibratile, ...

Gestion de la maintenance

L'installation a-t-elle fait l'objet d'un contrôle des équipements sous pression en service ?

Cocher la case correspondante

OUI		NON	

La maintenance est-elle externalisée ?

Cocher la case correspondante

OUI		NON	

Quelle typologie de maintenance appliquez-vous?

Cocher la case correspondante

Curative		Préventive systématique (sur agenda)	
Préventive conditionnelle (sur usure de pièce)			

Le contrat de maintenance inclut-il la recharge en fluide?

Cocher la case correspondante

OUI		NON	

Nous vous remercions pour votre participation à l'étude et vous prions de bien vouloir nous renvoyer ce document dûment complété et accompagné des fiches d'intervention :

- par mail : thomas.michineau@cemafroid.fr
  ou
- par courrier : à l'attention de Thomas Michineau, à l'adresse indiquée en bas de page

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Appendix 2: Visit Report Template

Plant Containment Study			
Application			
Type of plant			
Document review		**YES**	**NO**
Survey responses checked			
Final implementation file available			
Maintenance logbook available			
Job sheets available			
Maintenance contract available			
Visual inspection of plant	**Check points**	**Good overall condition**	**Poor condition Risk of leakage**
Evaporator (return bends)	Corrosion point, surface defect, vibration, impact		
Condenser (return bends)	Corrosion point, surface defect, vibration, impact		
Shut-off valves	Visual inspection of the packing gland. Cap present or not		
Schrader valves	Valve core, plug present or not		
Flare joint	Visual inspection of flare tightening, flare surface defect		
Mechanical joints and flanges (filter drier)	Visual inspection of bolt tightening		
Pressure Relief Valve (PRV) (or fusible plug)	Core-disc connection Presence of discharge indicator		
Shaft seal (open type compressors)	Oil loss from slip ring, shaft seal fitting, shaft alignment		
Line tap valves	Pipe condition, size of tap relative to pipe, loosening due to vibration		
Pressure switches	Coupler condition, bellows, flare connection, mounting support		
O-rings (sight glasses, solenoid valves)	Hardening or flattening leakage due to reaction to the new oil (retrofitting)		
Capillary tubes (connection of measuring instruments or expansion devices)	Fixing problems Defective weld/fitting		
Suction line	Suction line corrosion due to condensation		
Refrigerating circuit	Presence of corrosion points Anti-vibration hanger, anaconda		
Feedback on past leakage	**Free comments**		
Plant owner			
Refrigeration technician			
Maintenance	**Free comments**		
Plant owner *Plant owner's general assessment on the quality of maintenance work performed on his facility*			
Leak testing report	**Free comments**		
Auditor			

Appendix 3: Reference Material Review Sheets

Appendix 3 is attached in a separate file

Appendix 4: Completed Visit Sheets

Appendix 4 is attached in a separate file

- District Cooling / Air conditioning system: Sheets n°1, 4, 6 et 18
- Cold stores: Sheets n°3, 9, 10, 11 et 14
- Commercial Refrigeration: Sheets n°5, 8, 12, 13, 16 et 17
- Food Industry: Sheets n°2, 7, 15

Appendix 5: Sheets by Sector

Sectoral Sheets							
	Field:	Commercial Refrigeration					
	segment	Centralised, direct/indirect expansion system in positive & negative refrigeration					
SYSTEM DESCRIPTION							
	Average load (Kg)	300 to 1,000	Refrigerant used	R404A	R507A		
	Refrigerant bank in France	1,780 tonnes	GWP	3700	3800		
MAIN CAUSES OF LEAKAGE							
Causes of leakage	Heat exchangers	Terminals (cold room evaporators, refrigerated display cabinet evaporators, equipment connected with positive and negative loops). On the positive loop, the (copper) evaporators of proof cabinets (chamber for storage of dough pieces for bakery products) are often porous. On the negative loop, ice machines (for seafood display) are often souvent incriminated.					
	Pressure tapping connection	Too many Schrader connections increasing the risk of leakage					
	Pressure-relief valve (PRV)	PRV does not reseat when the pressure drops					
	Compressor shaft seal	General wear of the shaft seal over time, increased oil loss from the slip ring. Lubrication failure. Incorrect fitting of a new shaft seal. Incorrect shaft alignment.					
	Pressure switches	Vibration causing the pressure coupler to split or damage to the pressure switch. Pressure coupler chafing. Rupture of the switch bellows due to vibration or hydraulic action. Failure of the flare connection. Poorly supported or fixed pressure switch.					

RECOMMENDATIONS			
Plant/equipment life cycle	Design	Accessibility	To facilitate maintenance provide access to the entire plant including distribution networks. Prohibit trenches and underground networks.
		Vibration	Reduce vibration, which is a major source of fatigue on piping systems and is the cause of many leaks. Install equipment on pads and piping on anti-vibration hanger.
		Material	For proof cabinets preferably use stainless steel evaporators rather than copper evaporators.
	Installation	Personnel	Assembly personnel must be qualified and welders have proper authorisation, which means that they should at least hold a certificate of capability. In-service monitoring of pressure equipment helps prevent risks, personnel should be trained and authorised.
		Procedures	Tighten flanges to the torque prescribed by the manufacturer Protect the soldered member with a damp cloth to prevent damage to the seal.
		Detection	Leak detectors must be installed in the machinery room. To place the atmosphere detector sensors in the optimal position it is advisable to: - Perform a general diagnostic of the plant's condition with regard to leakage. - List the most sensitive components (e.g. valves, loading valve etc.) - Position the sensors as close as possible to those components - Take particular care in determining the required height of the sensor according to the type of gas it will detect (whether the refrigerant is heavier or lighter than air). Where possible use indirect leakage detection with alarm transfer.
	Operation	Maintenance	Give preference to "long-term" service contracts enabling any action implemented in leakage reduction to be written off over time and ensuring intelligent operation of the facility.
	Maintenance	Personnel	In-service monitoring of pressure equipment helps prevent risks, personnel should be trained and authorised
		Monitoring	Perform preventive maintenance and performance control, and submit a report to the equipment owner. Use due care in monitoring the plant (vibration, caps (and seals) improperly tightened or missing, etc.) and performing inspections (pre- and post-leakage). Knowing how to detect, perform or suggest preventive maintenance actions on sensitive parts and immediately correct any corrosion point is a key element. Leakage on connections often appears following a maintenance procedure; therefore, it is essential to conduct the leak test properly, using an electronic detector before leaving the facility.
	Dismantling	Recovery	On dismantling ensure that the entire refrigerant charge is recovered, as well as the oil, which must also be recovered for depollution.

Sectoral Sheets		
	Field:	Food industry: cooling processes, cold store etc.
	segment	Centralised, direct expansion system for positive or negative refrigeration

SYSTEM DESCRIPTION							
	Average load (Kg)	from a few hundred kgs to several tonnes	Refrigerant used	R404A			
	Refrigerant bank in France	5000	GWP	3700			

MAIN CAUSES OF LEAKAGE		
Causes of leakage	Heat exchangers	Terminals (cold room evaporators, refrigerated display cabinet evaporators, equipment connected with positive and negative loops). On the positive loop, the (copper) evaporators of proof cabinets (chamber for storage of dough pieces for bakery products) are often porous. On the negative loop, ice machines (for seafood display) are often souvent incriminated.
	Pressure tapping connection	Too many Schrader connections increasing the risk of leakage
	Pressure-relief valve (PRV)	PRV does not reseat when the pressure drops
	Compressor shaft seal	General wear of the shaft seal over time, increased oil loss from the slip ring. Lubrication failure. Incorrect fitting of a new shaft seal. Incorrect shaft alignment.
	Pressure switches	Vibration causing the pressure coupler to split or damage to the pressure switch. Pressure coupler chafing. Rupture of the switch bellows due to vibration or hydraulic action. Failure of the flare connection.

			RECOMMENDATIONS
Plant/equipment life cycle	Design	Accessibility	To facilitate maintenance provide access to the entire plant including distribution networks. Prohibit trenches and underground networks.
		Vibration	Reduce vibration, which is a major source of fatigue on piping systems and is the cause of many leaks. Install equipment on pads and piping on anti-vibration hanger.
	Installation	Personnel	Assembly personnel must be qualified and welders have proper authorisation, which means that they should at least hold a certificate of capability. In-service monitoring of pressure equipment helps prevent risks, personnel should be trained and authorised.
		Procedures	Tighten flanges to the torque prescribed by the manufacturer Protect the soldered member with a damp cloth to prevent damage to the seal.
		Detection	Leak detectors must be installed in the machinery room. To place the atmosphere detector sensors in the optimal position it is advisable to: - Perform a general diagnostic of the plant's condition with regard to leakage. - List the most sensitive components (e.g. valves, loading valve etc.) - Position the sensors as close as possible to those components - Take particular care in determining the required height of the sensor according to the type of gas it will detect (whether the refrigerant is heavier or lighter than air). Where possible use indirect leakage detection with alarm transfer.
	Operation	Maintenance	Give preference to "long-term" service contracts enabling any action implemented in leakage reduction to be written off over time and ensuring intelligent operation of the facility.
	Maintenance	Personnel	In-service monitoring of pressure equipment helps prevent risks, personnel should be trained and authorised
		Monitoring	Perform preventive maintenance and performance control, and submit a report to the equipment owner. Use due care in monitoring the plant (vibration, caps (and seals) improperly tightened or missing, etc.) and performing inspections (pre- and post-leakage). Knowing how to detect, perform or suggest preventive maintenance actions on sensitive parts and immediately correct any corrosion point is a key element. Leakage on connections often appears following a maintenance procedure; therefore, it is essential to conduct the leak test properly, using an electronic detector before leaving the facility.
	Dismantling	Recovery	On dismantling ensure that the entire refrigerant charge is recovered, as well as the oil, which must also be recovered for depollution.

Sectoral Sheets	
Field:	Domestic refrigeration, monoblock air-conditioning, small commercial refrigeration equipment
segment	Hermetic System

SYSTEM DESCRIPTION						
Average load (Kg)	150g to a few kg	Refrigerant used	R134a	R410A		
Refrigerant bank in France	2600 tonnes	GWP	1370	2100		

Causes of leakage	MAIN CAUSES OF LEAKAGE	
	Monoblock equipment	By definition, monoblock equipment is not supposed to leak ex-factory. Leakage may be caused by vibration due to the system operation or environment, and is mainly located on exchanger return bends or pressure switch connections, if applicable.

Plant/equipment life cycle	RECOMMENDATIONS		
	Design	Leak test	Always conduct a helium leak test.
		Vibration	Consider a piping route which would enable vibration to be absorbed (depending on the application considered).
	Installation	Personnel	Assembly personnel must be qualified and welders have proper authorisation, which means that they should at least hold a certificate of capability
	Operation	Maintenance	The operator, or owner of the facility should ensure that exchangers are cleaned on a regular basis.
	Maintenance	Personnel	Maintenance personnel must be qualified and welders have proper authorisation, which means that they should at least hold a certificate of capability
		Repair	When conducting work which requires replacement of a component (e.g. filter drier), keep the soldered connections rather than the screw-on connections to preserve the tightness of the equipment.
	Dismantling	Recovery	On dismantling ensure that the entire refrigerant charge is recovered, as well as the oil, which must also be recovered for depollution.

Sectoral Sheets		
Field:	Refrigerated Transport	
segment	Driven-belt unit	

SYSTEM DESCRIPTION						
Average load (Kg)	1,58	Refrigerant used	R404A			
Refrigerant bank in France	100 tonnes	GWP	3700			

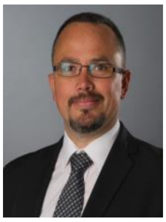
MAIN CAUSES OF LEAKAGE		
Causes of leakage	Refrigeration circuit	For driven-belt units, 29% of the leaks observed are located on pipework (pipes punctured due to vibration).
	Pressure tapping connection	Schrader connections are major sources of leakage (10% of the leaks observed).
	Compressors	General wear of the shaft seal over time, increased oil loss from the slip ring, amounting to approximately 40% of leaks.

RECOMMENDATIONS			
Plant/equipment life cycle	Design	Vibration	Reduce vibration, which is a major source of fatigue on piping systems and is the cause of many leaks.
	Installation	Procedures	Units are assembled in the factory. The main leakage sources originate from connection points (flexible couplers, ou additional evaporators where units are multi-temperature). Follow recommendations on how to assemble connections (lubricate seals).
		Detection	Test the refrigeration unit when it is connected, then inspect with leak detector after charging with refrigerant.
	Operation	Procedures	Units should not be shut down for an extended period of time as this might cause drying of the compressor shaft seals and therefore a risk of leakage.
	Maintenance	Monitoring	Use due care in monitoring the unit (checking belt tension, bearings, vibration, caps (and seals) improperly tightened or missing, etc.) and performing inspections (pre- and post-leakage). Leakage on connections often appears following a maintenance procedure; therefore, it is essential to conduct the leak test properly, using an electronic detector. When replacing the compressor shaft seal, be sure to follow the assembly recommendations and thoroughly lubricate the seal before replacing it.
	Dismantling	Recovery	On dismantling ensure that the entire refrigerant charge is recovered, as well as the oil, which must also be recovered for depollution.

Appendix 6: List of Consortium Experts who participated in the study

Cemafroid Experts

Name and Position	Education and Training	Experience and Qualification	References
Eric DEVIN  Managing Director – President, Cemafroid Formation	Engineering degree from Paris XI University at Orsay, in Materials Science & Engineering	Eric Devin began his career at the *laboratoire national d'essais* (LNE, French national testing laboratory), managing the metrology and testing laboratories in thermal engineering, head of the legal metrology division for 5 years. He actively participated in the opening to the European market under the New Approach directive. In late 2007, Eric DEVIN joined Cemafroid to contribute to its development, particularly in the area of certification, establishing Cemafroid as the number one accredited body on refrigerants. Eric Devin is an active member of the French Refrigeration Association (AFF), Chairman of AFF's Ile-de-France Committee (IDF), Chairman of IIR's CERTE subcommittee for transport, and Vice-President of UNECE's WP11 for the ATP Regulation. He also sits in the French Metrology Committee and is a member of the AFCE Board of Directors. He coordinates the Datafluides consortium which consists of four organisations authorised to deliver qualification certificates and concerns more than 12,000 companies in France	MINISTÈRE DE L'INDUSTRIE (DARQSI), MEEDE, CECOD, OIML, WELMEC, ISO, CEN, AFNOR, SYNDICAT DE LA MESURE, UNECE, INTERNATIONAL INSTITUTE OF REFRIGERATION, ASSOCIATION FRANÇAISE DU FROID, TRANSFRIGOROUTE FRANCE
Thomas MICHINEAU  Manager of the Expertise & Studies Unit	MBA in Marketing & Strategy, Ecole Supérieure de Commerce Extérieur (ESCE), IAE Poitiers Polytechnic School of the University of Nantes (EPUN) Thermal Engineering Department – Energy, with a specialisation in Refrigeration/Air-Conditioning	Thomas Michineau began as Deputy Head of the Scientific and Technical Information Department at the International Institute of Refrigeration (IIR). During this assignment he met most international experts of the refrigeration sector and participated in numerous conferences. He joined Cemafroid in 2012, where he was in charge of various studies (market studies on alternatives to compression units in transport, studies on the facilities of large and medium-size retail stores, magnetic refrigeration, European study. He manages the project for implementation of Cemafroid's new testing platform (ammonia CO_2)	EDF, IIR, UE

Florence MOULINS  Consulting Engineer	Strategic Marketing INM-IFG Post-graduate degree in Industrial Refrigeration, IFFI-CNAM Advanced Technician's Certificate in Refrigeration & Air-Conditioning	Director of Prescription France and Deputy Marketing Director of SANYO, then Director of OEMS Sales at TECUMSEH EUROPE, Florence then became Manager of Sales & Distribution and Product manager at ACAL SA and AC Technical Sales Engineer at TOSHIBA SYSTEMES SA before joining Cemafroid. A member of the French Refrigeration Association (AFF), Florence is Afnor certified for the inspection of heat pumps and air-conditioning systems. She is involved in numerous missions, including project development assistance, energy audits of retrofits, and retro-commissioning in France and Europe.	SANYO, TECUMSEH EUROPE, ACAL SA, TOSHIBA SYSTEMES SA,AFF
Frédéric VANNSON  Manager, Qualification Certificates & Inspection Unit	Advanced Technician's Certificate in refrigeration, la Martinière, Lyon, Trained at the Institute of Industrial Refrigeration (IFFI)	Refrigerants auditor, Heat Pumps & AC Inspector at Cemafroid since 2013, Technical Consultant at Petit Forestier 51995 TO 2012°	Petit Forestier

IRSTEA Experts

Name and Position	Education and Training	Experience and Qualification	References
Laurence FOURNAISON  Research Manager	Doctorate in Energetics, Paris VI (1991) HDR UTC Compiègne (2006)	After a doctorate in 1991 on cold storage, she conducted research work on cold storage and acquired expert skills on two-phase coolants. She launched and directed numerous national and international projects in the field of refrigeration, associating both academic and industrial partners. In 2011, she became Head of the Research Unit in Cold Process Engineering at Irstea, employing 30 people. She is an active member of AFF and chairs the international work group on phase changing materials of IIR.	CEMAGREF, IRSTEA, IIR
Anthony DELAHAYE  Research Engineer	Process Engineering Degree, ENSGTI Pau (1999) Doctorate in Process Engineering – Paris 13 (2002) HDR - Paris 6 (2013)	After working on the thermal effects of hydrogen storage during his doctoral thesis in chemical engineering at CNRS (LIMHP-Paris 13), Anthony Delahaye was hired in 2002 at Cemagref (formerly Irstea), where he collaborated on various national and international programs, specifically on grout and thermal storage (ice, hydrates, PCM) in secondary refrigeration. Since 2013, he has been in charge of the *Enerfri* team (energy efficiency of refrigeration systems) within Irstea's Research Unit in refrigeration process engineering. He has published 22 international peer-reviewed articles and 45 papers.	CEMAGREF, IRSTEA

<table>
<tr>
<td>Denis LEDUCQ

Research Engineer</td>
<td>Engineering degree, ENGEES (1989)

Doctorate in Process Engineering, AgroParisTech (2002)</td>
<td>After earning a Master’s degree in energetics and instrumentation control in 1998, followed by a doctorate in 2002, he is presently carrying out engineering and research work at Irstea, in Antony, and is involved in several national and European research programmes.

He is a co-founder and member of the management board for the RCR (Refrigerant Charge Reduction) workgroup of the International Institute of Refrigeration. He has written more than 50 scientific and technical publications in the area of refrigeration, energy efficiency improvement in refrigerating plants, and reduction in refrigerant charge.</td>
<td>CEMAGREF, IRSTEA</td>
</tr>
<tr>
<td>Romuald HUNLEDE

Design Engineer</td>
<td>Post-graduate degree in Industrial Refrigeration (DSFI), IFFI-CNAM

Advanced Technician’s Certificate in Refrigeration & Air-Conditioning, CFI des Richardets</td>
<td>After working several years as a fitter and service mechanic of refrigerating plants and AC systems, Romuald Hunlédé became a trainer for young apprentices at the CFI des Richardets (an Industrial Training Centre).

After earning his DSFI in 2004, he joined Irstea (formerly Cemagref) as a design and operations engineer in experimental techniques. His main missions include:
- maintenance management of the refrigerating plant base (environmental cells and experimental prototypes)
- expert assessment for communities and municipalities
- conducting studies on refrigerant mass reduction</td>
<td>ASSISTANCE PUBLIQUE DES HOPITEAUX DE PARIS, CHAMBRE DES COMMERCES ET D'INDUSTRIE DE PARIS, CEMAGREF, IRSTEA</td>
</tr>
</table>

ABOUT ADEME

The French Environment and Energy Management Agency (ADEME) is a public agency under the joint authority of the Ministry of Ecology, Sustainable Development and Energy, and the Ministry for Higher Education and Research. The agency is active in the implementation of public policy in the areas of the environment, energy and sustainable development.

ADEME provides expertise and advisory services to businesses, local authorities and communities, government bodies and the public at large, to enable them to establish and consolidate their environmental action. As part of this work the agency helps finance projects, from research to implementation, in the areas of waste management, soil conservation, energy efficiency and renewable energy, air quality and noise abatement.

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