Zero Leaks

Limiting Emissions of Refrigerants

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Limiting Emissions of Refrigerants

Denis Clodic



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Refrigerating and Air-Conditioning Engineers, Inc.

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FOREWORD

This book should be of interest to policy makers (What is reasonable to specify?), to analysts (What is reasonable to use in analyses?), and to practitioners of the trade (How tight can I make my systems?), all of whom are concerned about the effects of refrigerant leaks: the effect on refrigeration systems and the effect on the environment. For practitioners and non-practitioners alike, the book should provide an understanding of the leak phenomena and the limits on detection and correction or prevention of leaks. This is largely a matter of leaks of fluorocarbons, which are currently the dominant refrigerants in the global industry.

—

Over sixty years ago, the emerging refrigeration and air-conditioning industry switched to fluorocarbon refrigerants because they were believed to be environmentally benign, a belief that persisted for many years. With discovery of the ozone hole, confirming of the theory of Noble laureates Rowland and Molina, and with increased understanding of global warming, we have a new appreciation of the need to confine all refrigerants in tightly closed systems. This has brought an increased awareness of the need for rigorous leak control—ideally, absolute leak prevention.

Proponents of non-fluorocarbon refrigerants would argue that the concerns of global warming and ozone depletion could be alleviated through the use of refrigerants such as ammonia or hydrocarbons. This highlights the leak tightness paradox of the currently competing refrigerants:

- Fluorocarbons need tight systems to protect the global environment against the effects of ozone-depleting chemicals and greenhouse gases.
- Hydrocarbons and ammonia need tight systems to protect nearby people and property from the risk of fire, and in the case of ammonia, the risk of toxic exposure.

Put another way, the fluorocarbons must be contained to protect the global environment, and the alternatives must be contained to protect the local environment. In both cases, good system tightness is required.

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We need to limit emissions to the minimum attainable at an affordable cost. With better understanding generally

comes better affordability of tight systems. One reflection of this better understanding is that leak detection techniques of aerospace and vacuum technology are being applied more widely in the HVACR industries.

These techniques have been used for many years in the more sophisticated refrigeration and air-conditioning manufacturers' laboratories and production processes, and the use is expanding as the importance of refrigerant containment is emphasized. To aid in the move toward tighter systems, the author has assembled the fundamentals of the state of the art complemented by results of new research in his own laboratory and insights gained from field tests. The two recurring themes are: leak detection and leak prevention or correction.

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The book contains just enough theory—tailored to a results-oriented audience. It is a book targeted primarily at practitioners, not theorists. The development is largely non-mathematical, with a few simple, solved, differential equations for the mathematically inclined.

If you remember your physics, you know that there is potential energy associated with a pressurized gas in a container [$E = P \cdot V$]. The author has taken advantage of this to characterize leaks in terms of power (the rate of energy flow into, or out of, a system). Use of the microwatt as the unit of measure bridges the gap between those who think in metrics [cc/s] and those who think in Imperial units [$in.^3/s$].

—

The problems addressed in the book are real and very practical. Many systems leak early, often, and severely. In particular, a system that has been ineptly serviced or repaired is likely to lose a full charge. If the same inept mechanic returns to correct his errors, at least one more system charge is likely to be lost before the problem is corrected. For this reason, the author repeatedly stresses the importance of training of technicians and others who influence refrigerant containment.

Emphasis is placed on leak detection as the keystone of tight systems. To assure that designs and procedures are adequate to provide a truly tight system, it is necessary to be able to detect, locate, and measure any leakage so that the leaks can be corrected and the correction can be verified.

What, then, is the irreducible minimum leak? Part of the answer relates to the question: what is the minimum detectable leak? This, in turn, depends on the type of leak, its location, the nature of the gas that is leaking, the effort taken to accumulate the leaking gas for detection, the type of detector, the amount of time that is feasible for letting a detectable concentration of the tracer gas accumulate, and the skill of the operator. The author addresses all these questions, and where answers are not readily available, he makes sure that the reader knows the questions and proposes research to provide the answers. These are matters of quantification, not matters of understanding the underlying physics of the leak processes or leak detection.

—

The book addresses leak detection sensitivity showing that some favored leak test techniques fall short of the sensitivity needed to assure the containment of refrigerants.

Instrument accuracy and sensitivity under favorable laboratory conditions cannot necessarily be extrapolated to field conditions or even to other laboratory conditions. For example, the preferred leak detector in vacuum technology is the helium mass spectrometer. However, this instrument is relatively insensitive as a "sniffer" for measurement of leakage from a pressurized system into air, and helium may not be an appropriate model for refrigerant leakage, particularly when absorption of gases in lubricants is considered.

—

If we could learn to design and build intrinsically leak-proof systems, then we could relegate the leak detector to the laboratory. The techniques for making tight systems have been known and practiced in the aerospace industry for decades, but most of these systems have shorter service lives than refrigeration systems and are much more maintenance-intensive.

Progress has been slow in applying lessons from aerospace to the general manufacturing sector partly because of the need to avoid the cost structure of aerospace and partly because there was insufficient incentive to spend the extra resources needed to tighten the systems and to assure their tightness. The global environment imperative now provides that incentive, and industry is challenged to ferret out the knowledge and apply it.

We need good detectors to guide our progress down that path and resources like this book to use as road maps for the journey. The author's goal is to set a beacon to light the path. This goal is reflected in the publication of this book in both French and English, with the hope of reaching the majority of the global HVAC industry. In the spirit of internationalism, I wish the reader bon voyage.

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ASHRAE Member
April 1997

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This book is based on the work performed by a team of technicians and engineers of the Center for Energy Studies of the Ecole des Mines de Paris.

They have spared neither their time nor their efforts. They are J.-C. Loyer and F. Fayolle, technicians; M. Ben Yahia, doctor engineer; and P. Pœuf and O. Gaveau, engineers. They have provided much of the data presented in this book.

Leak tightness control is based on the quality of measurement devices. M. J.-F. Joanin, from SAPRE Co., always answered our questions and was able to develop several new devices.

All the work was performed as part of research contracts and studies.

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The book has been created with the participation of Ph. Calvet—pictures and illustrations; F. Fayolle—drawings; and A.-M. Pougin and C. Siri—editing, layout, and artwork.

Pictures of components and equipment are copied from commercial documentation of Alcatel, Carrier, Matal, NRP, Sapre, Sulzer, Trane, VTI.

INTRODUCTION

This book gathers the results of field and laboratory experiments, presents an original method for measuring leak rates of components of refrigerating systems, concisely reviews the equations necessary to estimate leak rates, and synthesizes recent regulations on the limitation of refrigerant emissions.

A study of 200 chillers has been the source of useful and broad experience on how to succeed in limiting and reducing refrigerant losses. Work done by the Center for Energy Studies of the Ecole des Mines de Paris, complemented by the experience of some twenty operators and two chiller manufacturers, have permitted the definition of specifications for equipment with improved tightness, designs for the manufacture of high-efficiency refrigerant recovery equipment, and the establishment of procedures that dramatically reduce refrigerant losses associated with chiller operation and maintenance.

An easy method has been developed for leak detection on centralized systems of hypermarkets, a historically difficult refrigeration application. A fruitful collaboration with the technical manager of the hypermarket group highlighted major factors to take into account in considering the structure of emissions in this application sector.

Refrigerant recovery from mobile air-conditioning systems and a confirming bench test have been performed. These investigations have provided a better understanding of the distribution of refrigerant emissions in such systems.

The experience gained in performing on-site studies provides invaluable data and feedback, which permits ranking emission reduction strategies.

This book synthesizes different methods of tightness measurement to establish easy methods to keep leak rates below defined thresholds and to define the appropriate metrology to measure leak rates using refrigerants as tracer gases.

First results from a test bench show that leak rates on the order of 1 gram per year can be measured with an accuracy of $\pm$ 10% on refrigerating components such as hoses, valves, or fittings.

Application of lessons learned, results of measurements, analysis of control methods, and calculation of leak rates are practical and theoretical benefits that make possible the definition of emission limitation policies adapted to different refrigerating systems.

Chapter 1

Zero Leaks—New Stakes

The Montreal Protocol and its revisions resulted in the phaseout of chlorofluorocarbons (CFCs) in developed countries at the end of 1995 and agreed that production of hydrochlorofluorocarbons (HCFCs) will cease. Several European countries have shown a willingness to ban HCFCs earlier than scheduled. Because of these decisions, more than 90% of the refrigerants used today will not be used in the future. Ammonia—with very specific uses in food processing—remains an acceptable fluid under more restrictive conditions.

For almost ten years, the chemical industry and the compressor and equipment manufacturers have been conducting research and development programs in order to select new refrigerants and to adapt components and systems to these new refrigerants.

As major changes take place in response to the CFC and HCFC phaseouts, a new question arises in the context of the Climate Convention signed in Rio in 1992: Should greenhouse gas contributions of hydrofluorocarbons (HFCs) limit choice of refrigerants?

The GWP (global warming potential) index was created to estimate the direct atmospheric contribution to the greenhouse effect of different gases compared with CO_2.

Major man-made greenhouse gases and their contribution to the greenhouse effect are CO_2 (more than 62%), methane (20%), nitrous oxide (4%), CFCs (12%), and HCFCs and HFCs (0.05%).[12]

If CFCs are replaced by HFCs and if emission rates remain high, the contribution of new refrigerants will grow to be in the range of 3% to 4%. While this contribution is small, it is not negligible, and the use of HFC refrigerants will almost certainly be subject to emission limitation policies.

1.1 Environmental Indices

Experts in atmospheric chemistry have developed three indexes—ODP, GWP, and TEWI—as guides to help decision makers:

ODP (Ozone Depletion Potential)

"Ozone depletion potential" is a relative scale that ranks chemicals based on their potential to deplete the ozone layer. By definition, R-11 has a value of 1 and is

TABLE 1.1
GWP of the Most Common Refrigerants[12]

Chemical Species	Formula	Atmospheric Life Time (years)	GWP 100 years
Carbon dioxide	CO_2	> 120	1
Methane	CH_4	14.5 ± 2.5	24.5
CFC-11	$CFCl_3$	50 ± 5	4,000
CFC-12	CF_2Cl_2	102	8,500
CFC-115	C_2F_5Cl	1,700	9,300
HCFC-22	CF_2HCl	13.3	1,700
HCFC-123	$C_2F_3HCl_2$	1.4	93
HFC-32	CH_2F_2	6	580
HFC-125	C_2HF_5	36	3,200
HFC-134a	CH_2FCF_3	14	1,300
HFC-152a	$C_2H_4F_2$	1.5	140
HFC-143a	CF_3CH_3	55	4,400

Note: values for HFC- or HCFC-blends are presented in Appendix 1, which also gives the main physical properties of these refrigerants.

the reference for all other chemicals (gases).

GWP (Global Warming Potential)

"Global warming potential" classifies gases based on their contribution to the greenhouse effect. CO_2 is the reference gas with a value of 1, so this value for each gas is expressed in kg of CO_2. The GWP value for any particular gas depends on the selected time frame. Table 1.1 gives the GWP of several refrigerants drawing from the 1994 IPCC (Intergovernmental Panel on Climate Change) report. Uncertainties in GWP are ±35%.

Natural emissions of greenhouse gases (mainly CO_2 and CH_4), combined with water vapor and clouds, maintain an average temperature on earth at +15°C. Since the pre-industrial era (1850), the emissions due to human activity, called "additional contributions," have increased sharply (see Figure 1.1).

Estimated additional contributions to the greenhouse effect since the pre-industrial era, expressed in equivalent thermal flux, have been:

- carbon dioxide (CO_2): 1.56 W/m^2,
- methane (CH_4): 0.5 W/m^2,
- nitrous oxide (N_2O): 0.1 W/m^2,

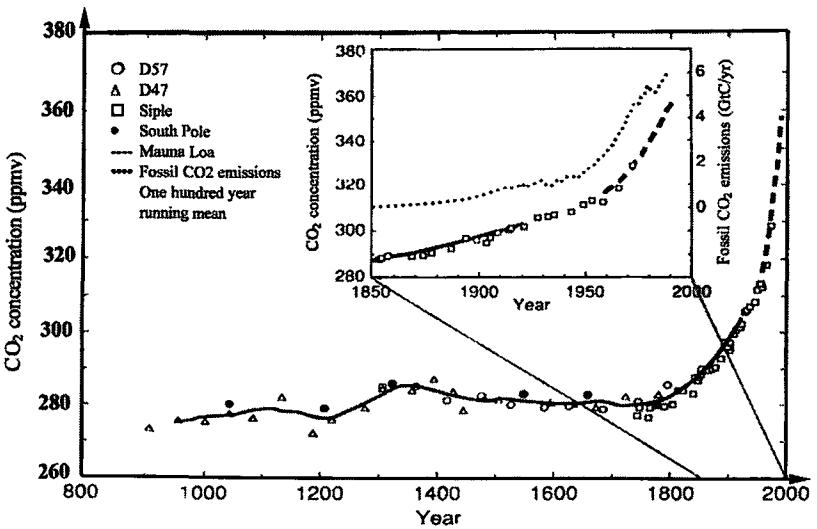


Figure 1.1 *Increase of the atmospheric CO_2 concentration.*[2]

- CFCs: 0.3 W/m^2,
- combined contributions of HCFCs and HFCs: lower than 0.05 W/m^2 due to their low concentration in the atmosphere.

As shown in Table 1.1, the GWPs of refrigerants vary widely. They depend on the atmospheric lifetime of the gas before it decomposes and on its infrared absorption.

TEWI (Total Equivalent Warming Impact)

The "total equivalent warming" contribution to the greenhouse effect has to be estimated over the lifetime of a system. Some studies show that the major global warming contribution of refrigerating and air-conditioning systems is due to energy consumption.[12,4,7,8] Each electric kWh consumed implies CO_2 emission, depending on the energy production structure of a given country.

The TEWI index was created to combine the direct contribution of refrigerating systems due to refrigerant emissions and the indirect contribution due to the energy consumption of these systems.

The GWP evaluation uncertainties noted above lead to significant uncertainties in the TEWI, to which are added uncertainties in emissions evaluation and energy consumption. The accuracy of these estimates for a given application depends on the number of installations, leak rates, hours of system operation, and the actual energy consumption and power source.

In Appendix 2, an example of a TEWI calculation for a domestic refrigeration