Forschungsrat
Kältetechnik

Research Project Commissioned by the

FORSCHUNGSRAT KÄLTETECHNIK

(RESEARCH COUNCIL FOR REFRIGERATION TECHNOLOGY)

Tightness of Commercial Refrigeration Systems

Ralf Birndt, Rolf Riedel, Dr. Jürgen Schenk, Dresden

Author
Dipl.-Ing. Ralf Birndt,
Researcher Materials/ Measuring Technology Department
ILK Dresden

Author
Dipl.-Ing. Rolf Riedel,
Researcher Materials/ Measuring Technology Department
ILK Dresden

Author
Dr. rer. nat. Jürgen Schenk,
Head of Materials/ Measuring Technology Department
ILK Dresden

The following article discusses and summarizes the extensive results of the recent AiF (industrial research association) research project "Tightness of Refrigeration Systems"[1], which was conducted by the Institut für Luft- und Kältetechnik (institute for air handling and refrigeration technology) in Dresden, commissioned by the **FORSCHUNGSRAT KÄLTETECHNIK (Research Council Refrigeration Technology).**

Tight refrigeration systems are necessary for technical, ecological and economic reasons, tightness is an essential quality feature of the systems. Within the EU, the EC Council in agreement with the European Parliament presently discusses proposals regulating the future use of CFCs and HCFCs.

---

[1] The report of the AiF research project No. 11340 "Dichtheit von Kälteanlagen (Tightness of Refrigeration Systems)" is available from the Forschungsrat Kältetechnik, Lyoner Str. 18, 60528 Frankfurt, Fax: 0049 69 6603 2276, e-mail: karin.jahn@vdma.org.

The term use here means the application of refrigerants in new systems or for the maintenance of old systems. The operation of tight refrigeration systems with “regulated“ refrigerants is permissible.

The clear statement by the BMU (Federal Ministry of the Environment) has to be understood accordingly: Only tight systems--and these without special regulations--will survive [1].

Beyond the restrictions with regard to refrigerants, regulations requiring periodic leak tests for stationary systems with a refrigerant charge of more than 3 kg are being discussed. This provokes questions about

- minimum requirements for the qualification of the test personnel

- the determination of allowed leakage rates and derived from this

- methods and equipment for leak detection.

From the above it can be deducted that the results of the research project “Tightness of Refrigeration Systems“, which was initiated by the Forschungsrat Kältetechnik, are of extraordinary importance and relevant to the present situation. Some of the results of the research project will be presented below.

Tightness

Selection of Systems, Test Methods

Statistical methods were used to select the refrigeration systems to be evaluated. The target was to obtain representative data which can be generalized with regard to the tightness of commercial refrigeration systems in Germany. The regional selection was done in a multistep sample survey:

1st stratum:
German states, Hesse and Saxony were selected

2nd stratum:
at least two districts per state, Frankfurt/Main and the surrounding area and Dresden and the surrounding area

The investigations in detail:

Hesse

9 refrigeration systems in supermarkets (compound systems)
built in: 1991 to 1999
charges: 88.4 to 150 kg

22 refrigeration systems in supermarkets and other commercial refrigeration systems (decentralized systems)

built in: 1990 to 1998
charges: 4 to 25 kg

11 refrigeration systems in supermarkets (decentralized systems--converted old systems)
built in: 1978 (conversion in 1997)
charges: 3 to 12 kg

Saxony

10 refrigeration systems in supermarkets (compound systems)
built in: 1995 to 1998 (1 system of 1996--conversion in 1999)
charges: 60 to 360 kg

10 refrigeration systems in supermarkets (decentralized systems)
built in: 1990 to 1996
charges: 0.7 to 17.3 kg

For statistical reasons (statistical certainty, assessed reliability) at least 5 refrigeration systems per state and category were evaluated.

With regard to the measuring technology to be used, the following requirements had to be fulfilled:

- A reliable localization of the leaks at the accessible parts of the refrigeration systems has to be feasible in as little time as possible.

- A quantification has to be possible for both large (magnitude of quantity kg/a) and small leak rates (< 30 g/a).

- In the presence of impairing gas concentrations, it needs to be possible to prove the existence of the refrigerant selectively.

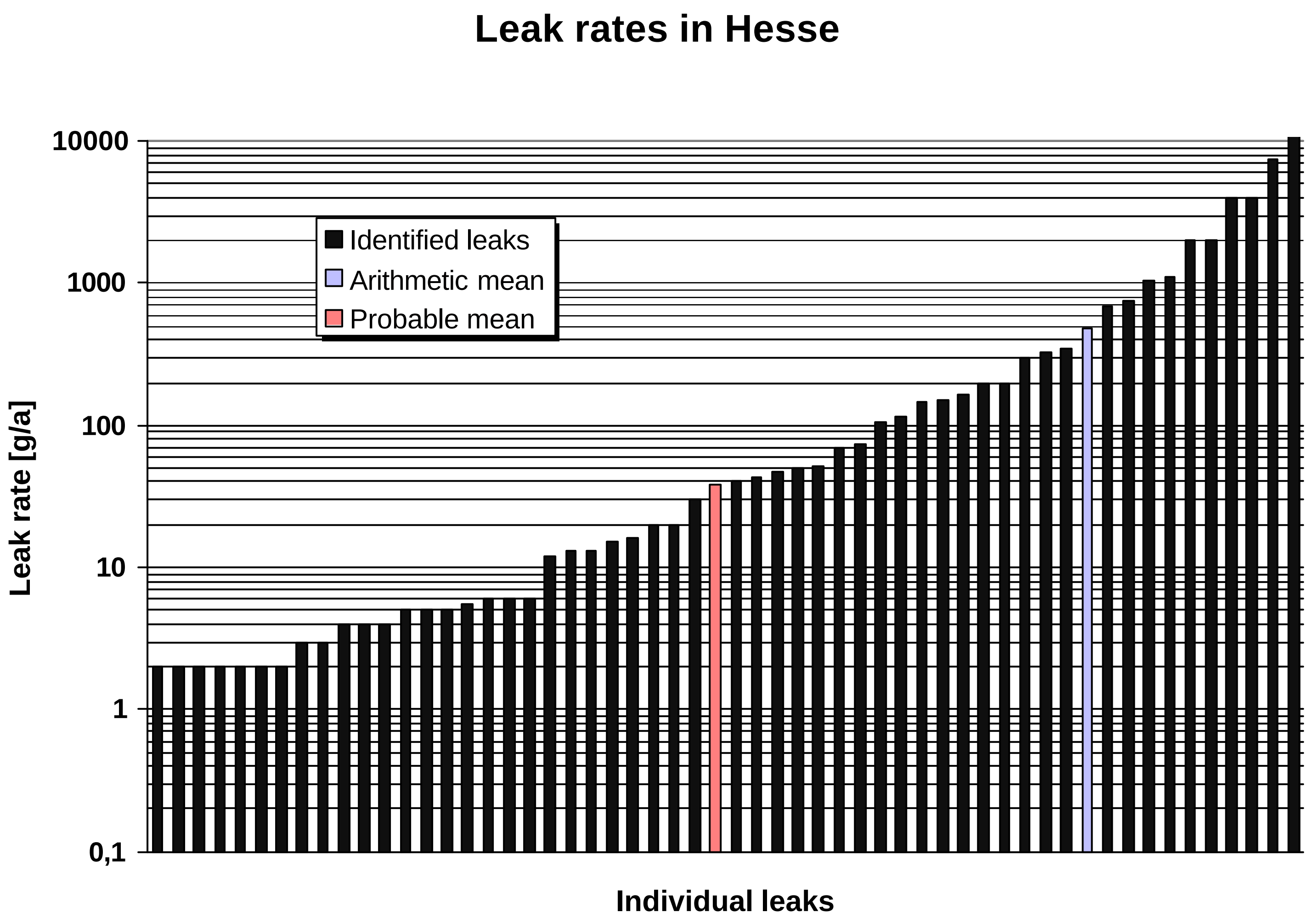
In order to meet these requirements, the following equipment was used:

1. Halogen leak detector HL4 by Hochvakuum Dresden (R22),
2. Halogen leak detector H25C by Yokogawa,
3. Selective gas detector Ecotec 500 by Leybold.

With this equipment, it was possible to achieve dynamic detection efficiencies of 1 g refrigerant/a and stationary detection efficiencies of 0.3 g/a. In isolated cases, the assembly leak detector D-Tec by Leybold-Inficon was used.

Evaluation of Individual Leaks

In 25 of the total of 62 tested refrigeration systems, no leaks were identified. In 37 refrigeration systems, 104 leaks were found in the range of 0.5 to 10,000 g/a and one leak of 540,000 g/a.



The individual evaluation of the states showed almost identical damage diagrams. This is made clear by the semi-logarithmic diagrams in figures 1 and 2.

Figure 1 Leak rates in Hesse

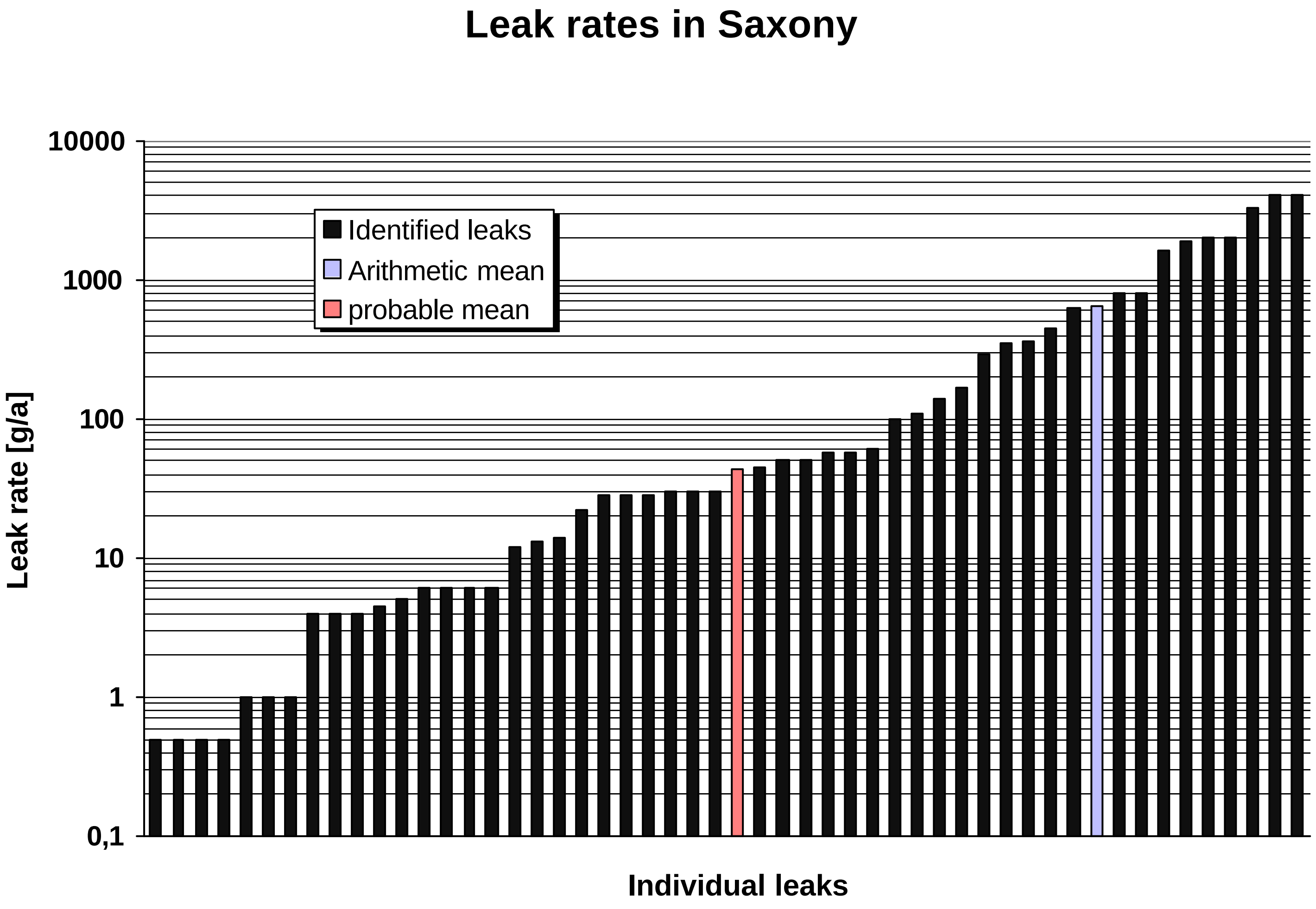


Figure 2 Leak rates in Saxony

The figures show that there are no significant differences in the two states with regard to tightness of supermarket refrigeration systems. Thus, it is very likely that the measured data can be regarded as representative for Germany.

The evaluation of the identified leaks according to leak rate areas results in the distribution reflected in figure 3.

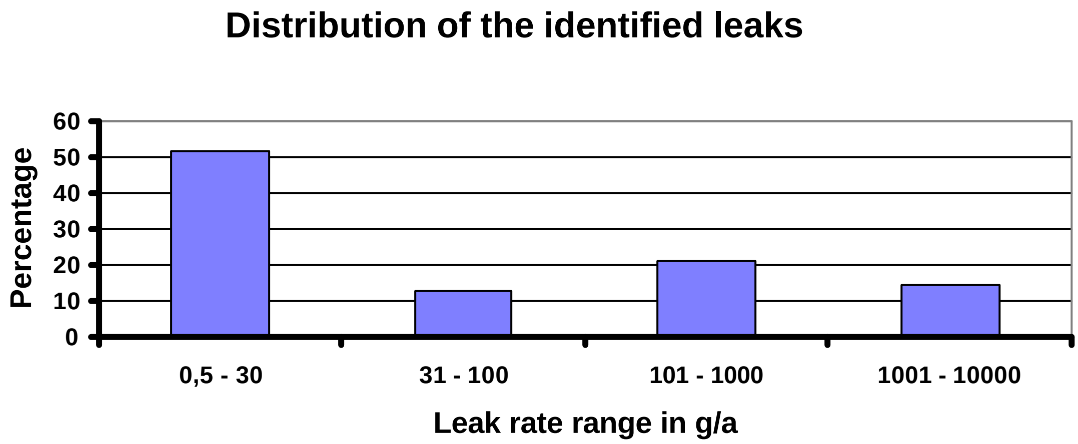


Figure 3 Distribution of the identified leaks

More than half of all the leakages are in the range of 0.5 to 30 g/a. As far as systems technology, ecological and economic aspects are concerned, this range can virtually be disregarded. This is made clear by the fact that these 51.9% of all leaks contribute only with 1 percent to the total leakage.

On the other hand, it has to be stated that 14.4% of the identified leaks in the range of 1,001 to 10,000 g/a make up 85% of the refrigerant loss in the systems.

This corresponds with the results of the statistical evaluation. The leak rates of the investigated systems are within the normal logarithmic distribution. This results in a 95% predictability that the mean of all leaks is in a reliability range (confidence interval) between 25.3 and 66.9 g/a. The mean as the most frequent and thus the most probable leak rate for all leaks is 41.9 g/a (Hesse: 38.6 g/a; Saxony: 43.9 g/a).

It is interesting that of the 104 identified leaks 18 occurred in the cycle components and 86 in the assembly joints. Figure 4 shows the distribution in detail.

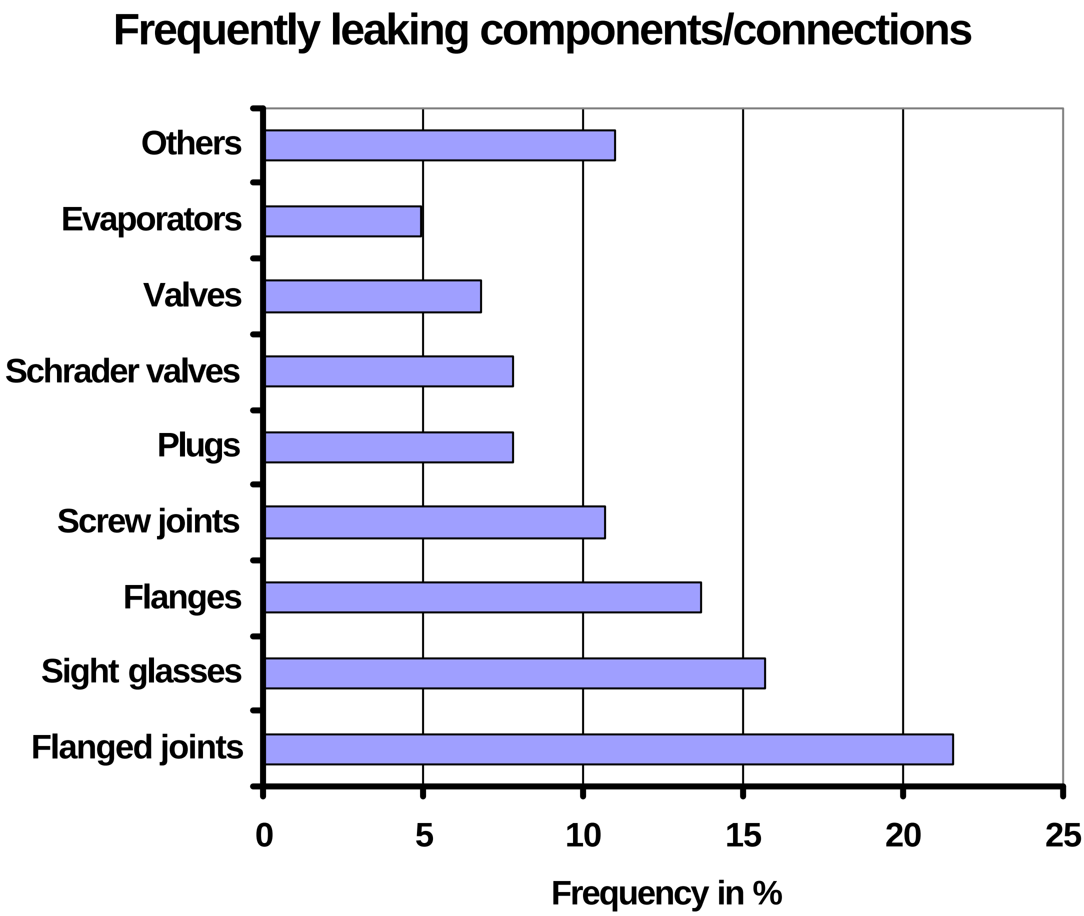


Figure 4   Frequently leaking components/connections

The refrigerant loss caused by system components/assembly connections and shown in figure 5 is of course of essential importance.

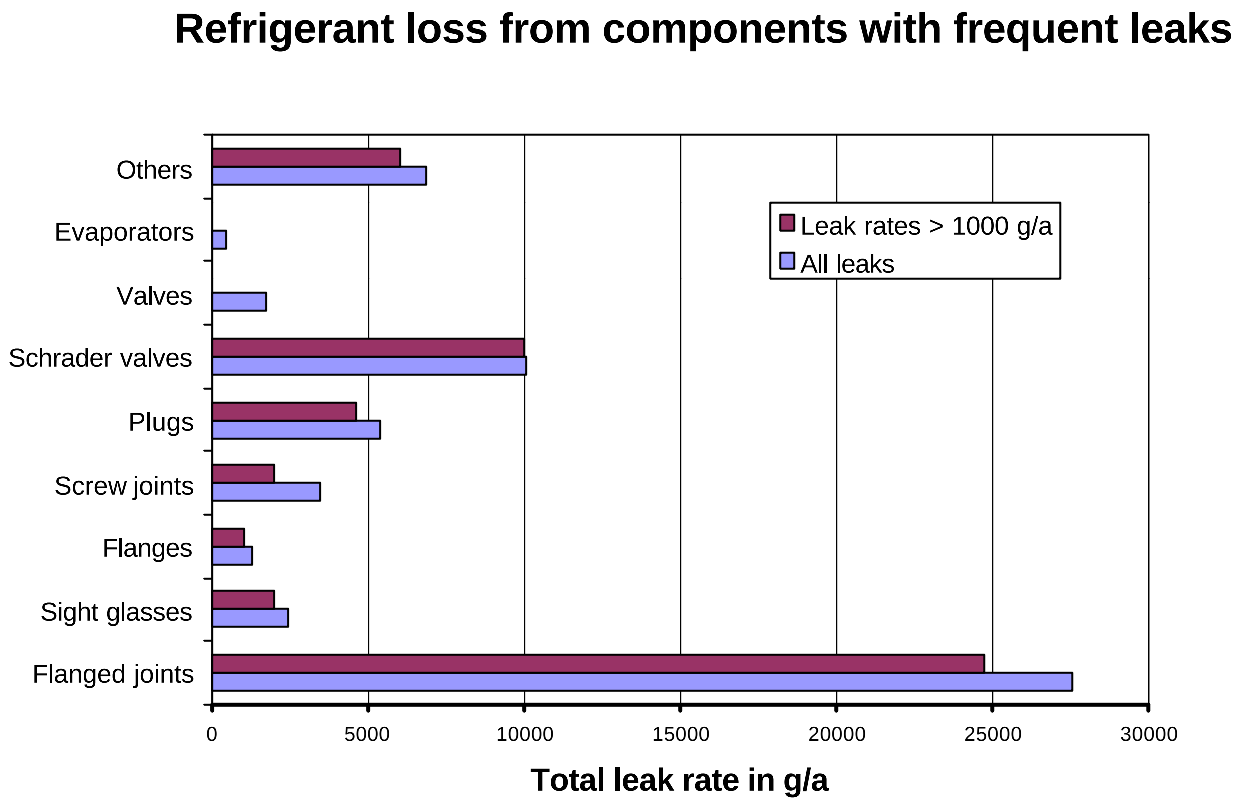


Figure 5 Refrigerant loss from components with frequent leaks

This evaluation shows as well that individual leaks of < 30 g/a have hardly any and even the individual leaks of < 100 g/a only an insignificant effect on the total leakage of the systems.

Specific Refrigerant Losses

The specific refrigerant loss can be calculated from the total leakage of a system taking the refrigerant charge into consideration. Here, it needs to be pointed out that additional refrigerant emissions can occur due to repairs and maintenance activities.

The refrigeration systems (compound systems) of supermarkets in Saxony and Hesse built from 1991 to 1999 with charges from 60 to 300 kg showed the following values:

Evaluation excluding accidents:
specific refrigerant losses 0 to 13.4%
mean specific refrigerant loss 2.3%

Evaluation including accidents:
specific refrigerant losses 0 to 100%

mean specific refrigerant loss 9.3%

The detailed graph is shown in figure 6.

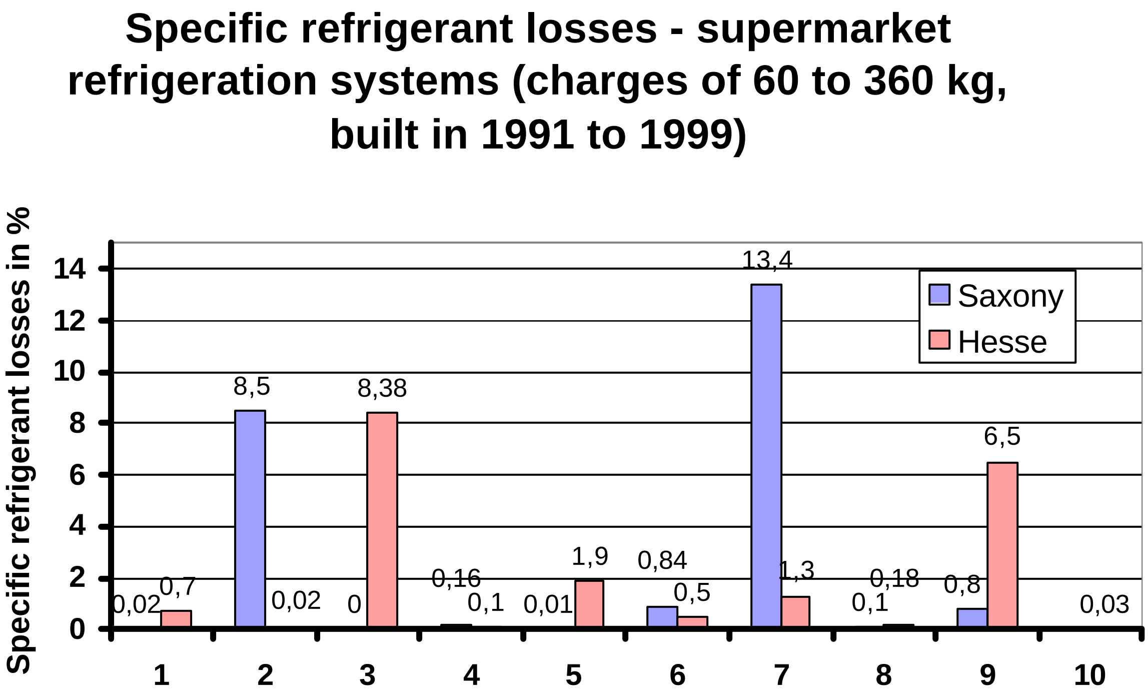


Figure 6 Specific refrigerant losses--
supermarket refrigeration systems (charges of 60 to 360 kg; built in 1991 to 1999)

In this context it is interesting that of the 19 investigated compound systems 15 show specific refrigerant losses of below 2%. 2 systems each in Hesse and in Saxony exceeded this value many times over.

Both in large and in small refrigeration systems leaks with leak rates of the same magnitude were identified. Thus, refrigeration systems with small refrigerant charges had clearly higher specific refrigerant losses, with the following effect on the results of all refrigeration systems:

Specific refrigerant losses for all investigated refrigeration systems excluding accidents	0 to 50%
Mean specific refrigerant loss	3.2%
Specific refrigerant losses for all investigated refrigeration systems including accidents	0 to 224%
Mean specific refrigerant loss	10.5%

Evaluation of the Results of Leak Tests

The results of the leak tests require reconsideration. On the one hand many systems showed no or only insignificant leakages, on the other hand do 15 leaks in the range of 1,000 to 10,000 g/a cause 85% of the total leakage of all investigated systems.

The state of the art offers no explanation for such large leaks in assembly joints, in any case they are unacceptable.

This result also shows, however, that if the below mistakes are avoided, there is a great potential to improve the tightness of these "bad" systems. The following can be regarded as the main reasons for the detected large leaks in the systems:

- As the detection sensitivity of the pressure drop test is overrated, a subsequent micro leak test with leak detectors is often regarded as unnecessary. Thus, leaks with very high leak rates (identified in the leak detection: leaks with 1 to 10 kg/a!) go undetected.
- The detection sensitivity of the coarse leak identification with soap solution is overrated, likewise the vacuum pressure rise test. The shortcomings of these tests are taken into consideration insufficiently.
- No environmentally benign solution yet exists for micro leak tests with refrigerant nitrogen blends and leak detectors in the field of on-site refrigeration system assembly.
- Micro leak tests with refrigerants at saturated vapour pressure and leak detectors are conducted only rarely.
- The capacities of the assembly leak detectors are known only insufficiently: No long term stability exists for the (investigated) assembly leak detectors. More than 50% of the investigated assembly leak detectors in use did not work properly (definitely too little detection sensitivity or inoperative).
- When maintenance is performed, often no attempt is made to detect leaks.

From these main causes we derive the following conclusions and recommendations to improve the tightness of systems:

- Careful assembly of separable connections, oil-free sealings! No use of screw joints with cylindrical windings.
- Further work towards more hermetic refrigeration systems. Hard-soldered joints have a very high sealing capacity and sealing reliability (failure rate < 0.5%).
- Flanged joints have to be connected carefully. Flanged joints have a very high sealing capacity but a lower sealing reliability.
- Development, manufacture and use of improved service valves (Schrader valves).
- A consistent avoidance or elimination of accidents (analyses, measures).
- The accessibility of refrigeration system pipings has to be ensured in principle (is practised by a prominent supermarket chain store), at least

stringent leak pre-tests of system components which are no longer accessible later.

- Correct evaluation of leak detection or leak test procedures.
- Performance of micro leak tests at highest possible pressure with halogen leak detectors (bench-mounted equipment) or inspected assembly leak detectors, which means inspection of the assembly leak detectors with suitable test leaks before each use.
- Enforcement of the principle that whenever maintenance is performed on a refrigeration system, it also has to undergo a check for leaks/leak test.
- Inclusion of refrigerated cabinets in leak detection of supermarkets (measurement of concentrations in chest type freezer cabinets and refrigerated display cabinets with stored food and inspection of the refrigerated shelves when vacant).

The above conclusions and recommendations are certainly no news for the refrigeration technology sector. However, if these principles had been consistently adhered to, 80 to 90% of the identified refrigerant losses could have been avoided.

It has to be mentioned that a refrigerant consumption report existed for only 5 of the 62 leak-tested commercial refrigeration systems, no log book existed for any of the systems.

Determination of Allowed Leak Rates

It is the usual practice in many technological fields (vacuum technology, chemical plants) to define allowed leak rates.

There is no absolute tightness. This is, for example, confirmed by the diffusion of hydrogen through the metal grid. According to [2] the term "tightness" is defined as follows:

"The testee is considered tight if, with the chosen test method and the required test efficiency or the detection efficiency corresponding to the method, a passage of the test agent from one room into the other or to the outside cannot be proved."

Thus, the following brief version of the definition can be given:

"A testee is tight if the allowed leak rate is not exceeded."

Starting out from the permissible leak rate, the required detection sensitivity can be derived and thus the test method be chosen.

It is known that in refrigeration technology, too, opinions differ very much as to when refrigeration systems can be considered tight, particularly since there are very small and very large refrigeration systems.

Especially refrigeration systems with large refrigerant charge reserves (as, for example, compound systems in supermarkets) are often spoken of as being “tight“ because no refrigerant had to be added for one or a few years.

The determination of allowed leak rates first of all refers to individual leaks. At the same time it is necessary, however, to determine tolerable specific refrigerant losses for the entire system. Here, not only the leakage losses but also the emissions due to repairs and maintenance have to be taken into consideration. In publications various recommendations can be found to this topic:

Schleswig-Holstein Ministry of the Environment (or the Factory Inspectorates)

In Schleswig-Holstein the Ministry of the Environment or the factory inspectorates estimate that the following specific refrigerant losses can be complied with:

In well maintained old systems
    specific refrigerant losses < 10 to 15%

In new systems
    specific refrigerant losses of about 2%

Status Report
TEWI Memorandum by the DKV (German Association for Refrigeration and Air Conditioning Technology) [4]

Premises TEWI refrigeration technology in 1986:
2005/scenario realistic with objectives (REAL)

For 2005 the following specific refrigerant losses (called “leak rates“ in the status report) are expected:

Application	Industrial	Automotive air conditioning	Household refrigeration	Commercial
Specific refrigerant losses	2.5%	10%	0.15%	2.5%

Swedish Proposal for the TEWI Appendix to prEN 378 [5]

The Swedish proposal of 1995 to the informative appendix “TEWI“ to prEN 378 recommended to regard specific refrigerant losses in dependence on the refrigerant charge. In an attached diagram the following figures were given

- about 8% specific refrigerant loss for charges of 3 kg
- about 5% specific refrigerant loss for charges of 10 kg
- about 2% specific refrigerant loss for charges of 200 kg.

EPA (Environmental Protection Agency):

Hitherto 35% (mean specific refrigerant loss) reduction to 10 to 15%.

The FMI (Food Marketing Institute) in San Antonio raised objections [6].

France:

Use of leak detectors with a “threshold sensitivity“ of 5 g/a [7].

The Netherlands:

Since January 1, 1994, the allowed specific refrigerant loss is 0.1 to 1% [8].

To what extent the latter figures are realistic will not be discussed more detailed at this point.

When the determination of allowed leak rates or of specific refrigerant losses is discussed, the emission reduction of environmentally harmful or damaging refrigerants occupies a special position. Realistically, however, the state of the art of attainable tightness in refrigeration technology, the present state of measuring technology and feasible testing technologies also have to be taken into consideration.

As the cycle components show a good tightness according to DIN 8964 and in principle a good tightness (good to excellent sealing capacity of the construction joints) can be achieved, the state of the art of attainable tightness does not require any consideration. It needs to be taken into consideration, however, that due to the present capacities of the assembly leak detectors, it is in general not possible to identify leaks < 30 g/a with certainty and thus no allowed individual leak rate of < 30 g refrig./a can be determined. Therefore, a determination of the allowed individual leak rate at 30 g refrig./a (referring to the saturation pressure of the refrigerant at room temperature) is proposed.

As DIN 8964 does already give allowed leak rates for cycle components, the determination of isolated leak rates only refers to joints of the refrigeration system. This is based on the assumption that about 0.15% of the hard-soldered joints reach the limit of the allowed individual leak rate.

At present many tests in the field of local installation of refrigeration plants can at the most be performed with refrigerants as test gases and with assembly leak detectors at a test pressure amounting to the saturation pressure corresponding to the ambient temperature. Therefore, it is necessary to apply the allowed individual leak rate to the saturation pressure of the refrigerant at room temperature. As the leak rate is square-law to the pressure, correspondingly higher values of the specific refrigerant losses of the system have to be tolerated.

As a rule, the specific refrigerant loss is determined from the recharge after an extended operating time (e.g. 1 year). For a short-term determination of the specific losses, the individual leak rates would have to be added (plus emissions due to maintenance and repairs).

To determine the allowed specific refrigerant losses, the objective for a first stage is proposed.

Allowed specific refrigerant loss:

2% to 7% depending on the charge according to figure 7.

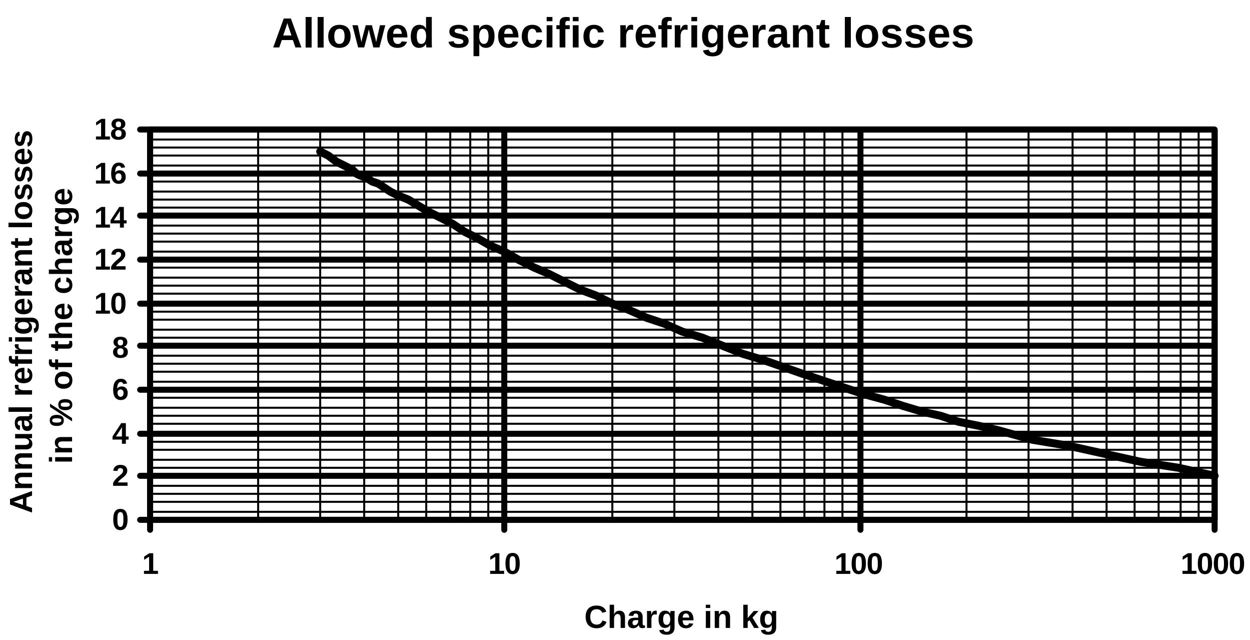


Figure 7 Allowed specific refrigerant losses

Summary

Commissioned by the Forschungsrat Kältetechnik, leak tests of selected commercial refrigeration systems, especially in supermarkets, were performed in the states Hesse and Free State Saxony.

Among other things the achieved results allow to

- give reliable information about the actual state of system tightness in this area,
- give recommendations for the applicable leak detection methods and the corresponding equipment,
- name problematic components and joining technologies,
- prepare proposals for allowed individual leak rates and specific total leak rates of commercial refrigeration systems.

References

[1] R. Engelhardt: CCI 2/2000, p. 4

[2] Dechema Informationsblatt ZfP1, Dichtheitsprüfung an Apparaten und Komponenten von Chemieanlagen, May 1988

[3] Klein, E., FCKW-Halon-Verbotsordnung bis Einsatzmengen von Kältemitteln beim Betrieb und bei Instandhaltungsarbeiten, Ministerium für Natur und Umwelt, Schleswig-Holstein, November 1995.

[4] Lotz, H., Beitrag der deutschen Kälte-, Klima-, und Wärmepumpentechnik zur Verringerung der Treibhausbelastung bis zum Jahre 2005, DKV-Statusbericht (TEWI-Memorandum des DKV), Nr. 13, April 1993.

[5] Swedish Refrigeration Foundation, Proposal for a new informative annex on TEWI prEN 378- part 4, “Selection of refrigerant“, CEN/TC 182/WG4, N58, 1995-08-10.

[6] Gentner-News 12.02.1999, “FMI widersetzt sich EPA’s Leckraten-Festlegung“, Gentner Verlag Stuttgart.

[7] French Ministry of Planning and the Environment, Draft decree about leak tests of components to ensure the tightness of refrigeration and air-conditioning systems which contain refrigerants. Notification 99/141/F. 12.03.1999, translated from French into German.

[8] “Regeling Lekdichtheidsvoorschriften Koelinstallaties“, (Herziening 1994), Bijlage Koude & Luchtbehandling jaargang 88 nr 1 (januari 1995), Pagina 1 - 8.

Forschungsrat Kältetechnik, Lyoner Str. 18, 60528 Frankfurt,
Tel. 0049 69 6603 1277, Fax 0049 69 6603 2276,
e-mail: karin.jahn@vdma.org

fkt/Artikel Dichtheit englisch CECOMAF/25.09.2001