Reducing emissions and leak of MAC systems: results from tests, lessons for servicing

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Center for Energy and Processes

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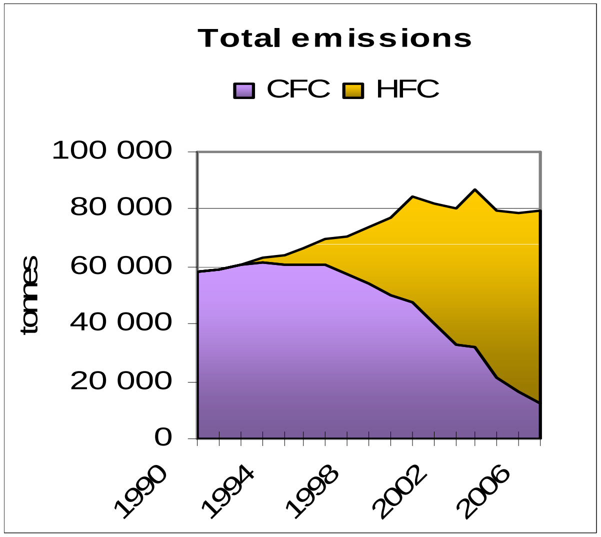
Contents

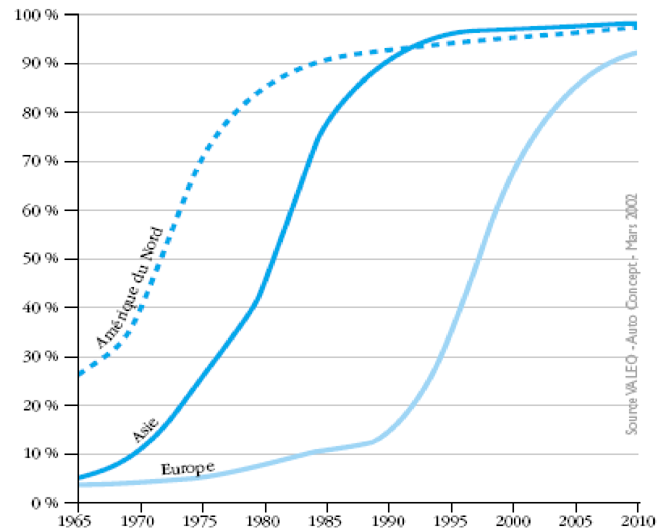
Global Refrigerant Inventories – RIEP model [CLO10]*

RIEP model – An emission-factor model using a bottom-up approach :

Equipment sales
Emission factors
Equipment technologies knowledge



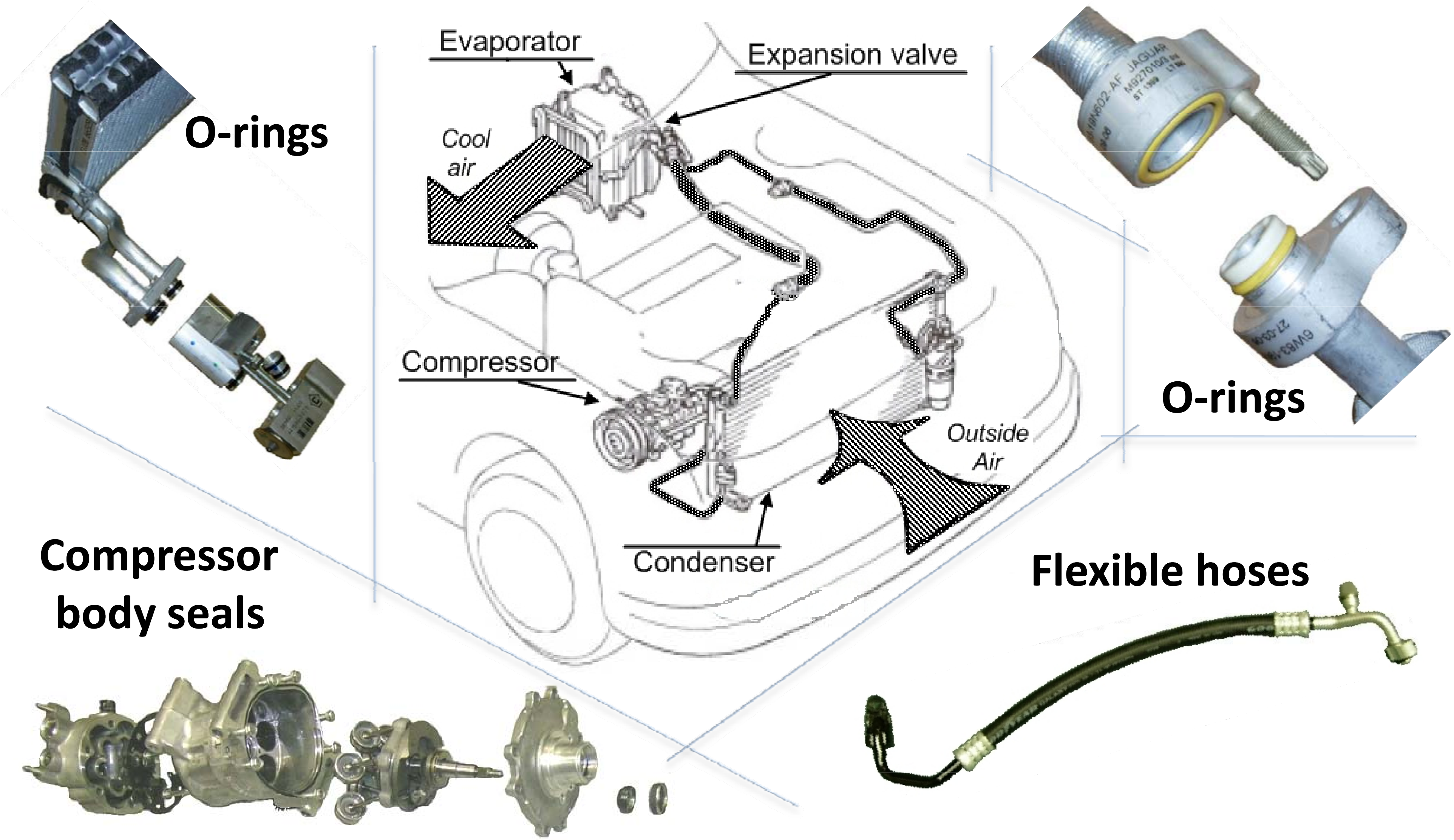
Total refrigerant emissions from Light Vehicles MAC systems



Typical penetration curves for MAC systems

* D. CLODIC, S. BARRAULT, S. SABA - Global inventories of the worldwide fleets of refrigerating and air-conditioning equipment in order to determine refrigerant emissions. The 1990 to 2006 updating, ADEME, April 2010

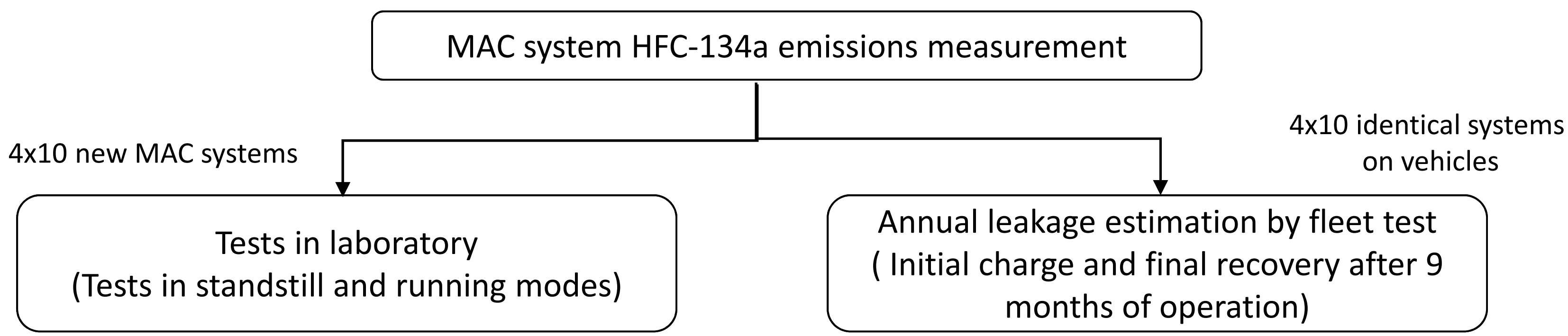
Sources of emission from Mobile Air-Conditioning (MAC) systems



MAC Systems – HFC-134a emissions

- 2006 CEP/ACEA [CLO07]* study done on:
  - 40 **new** vehicles
  - 4 x 10 system models

  Chosen by ACEA
  (European Association of Car Manufacturers)



EU commission test approval method to guarantee a maximum leak flow rate of R-134a of 40-60 g/yr for all MAC systems

Directive 40 / 2006 and Regulation 706 /2007

* CLODIC, Denis, YU, Yingzhong, TREMOULET, Arnaud and PALANDRE, Lionel. *Elaboration of a correlation factor based on fleet tests and mobile air-conditioning (MAC) system laboratory tests*. SAE World Congress & Exhibition, Session climate control (part 2 of 2), Detroit, USA, 16-19 april 2007, vol. SP-2132, n°2007-01-1187, p. 193 - 197

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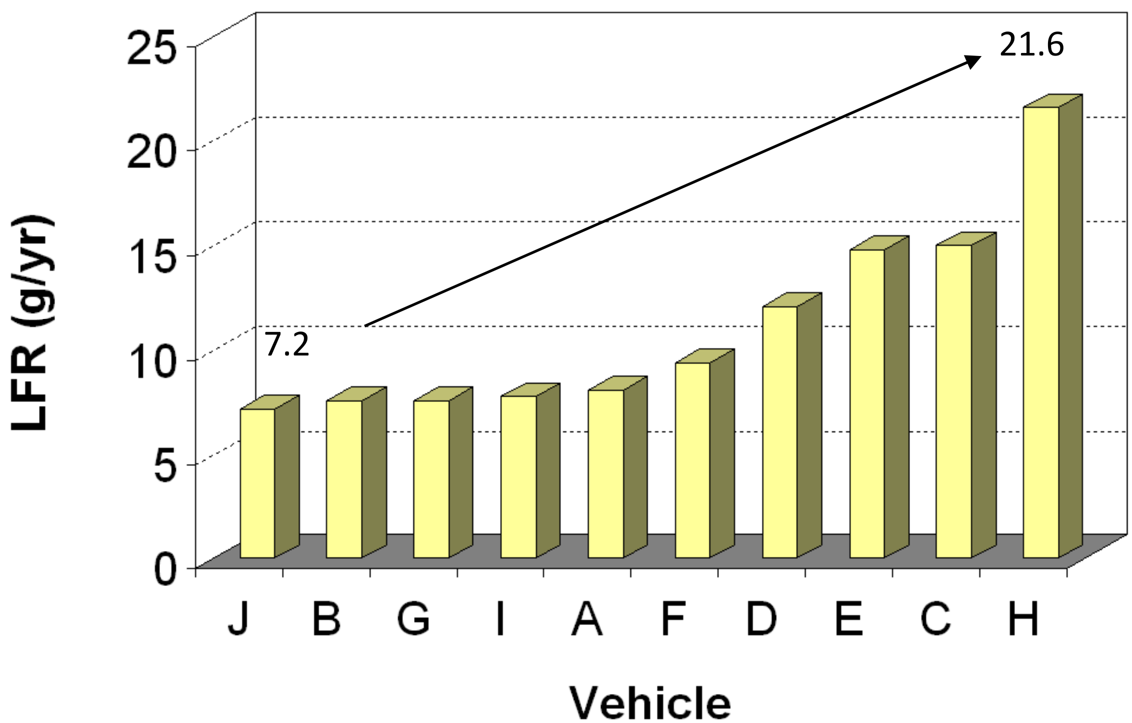
An accurate recovery method

- The recovery process has been validated on the 10 types of vehicles
- Initial charge performed within ± 0.5 g precision
- Operation of vehicle during 9 months
- Recovery 9 months after with a precision of 0 / -1g

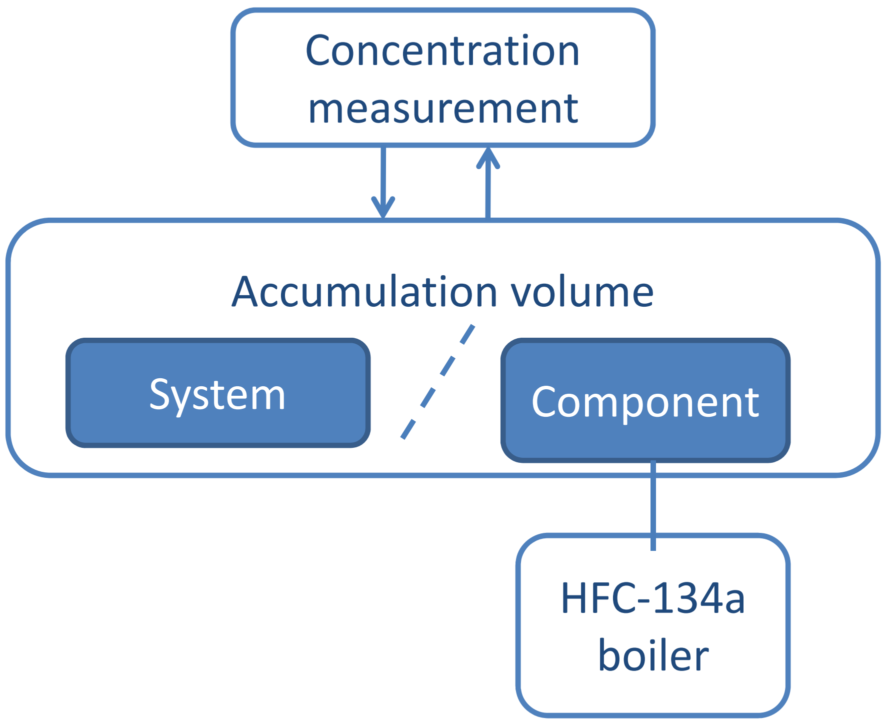
LFRmean = 10.0 g/yr



Tests in laboratory

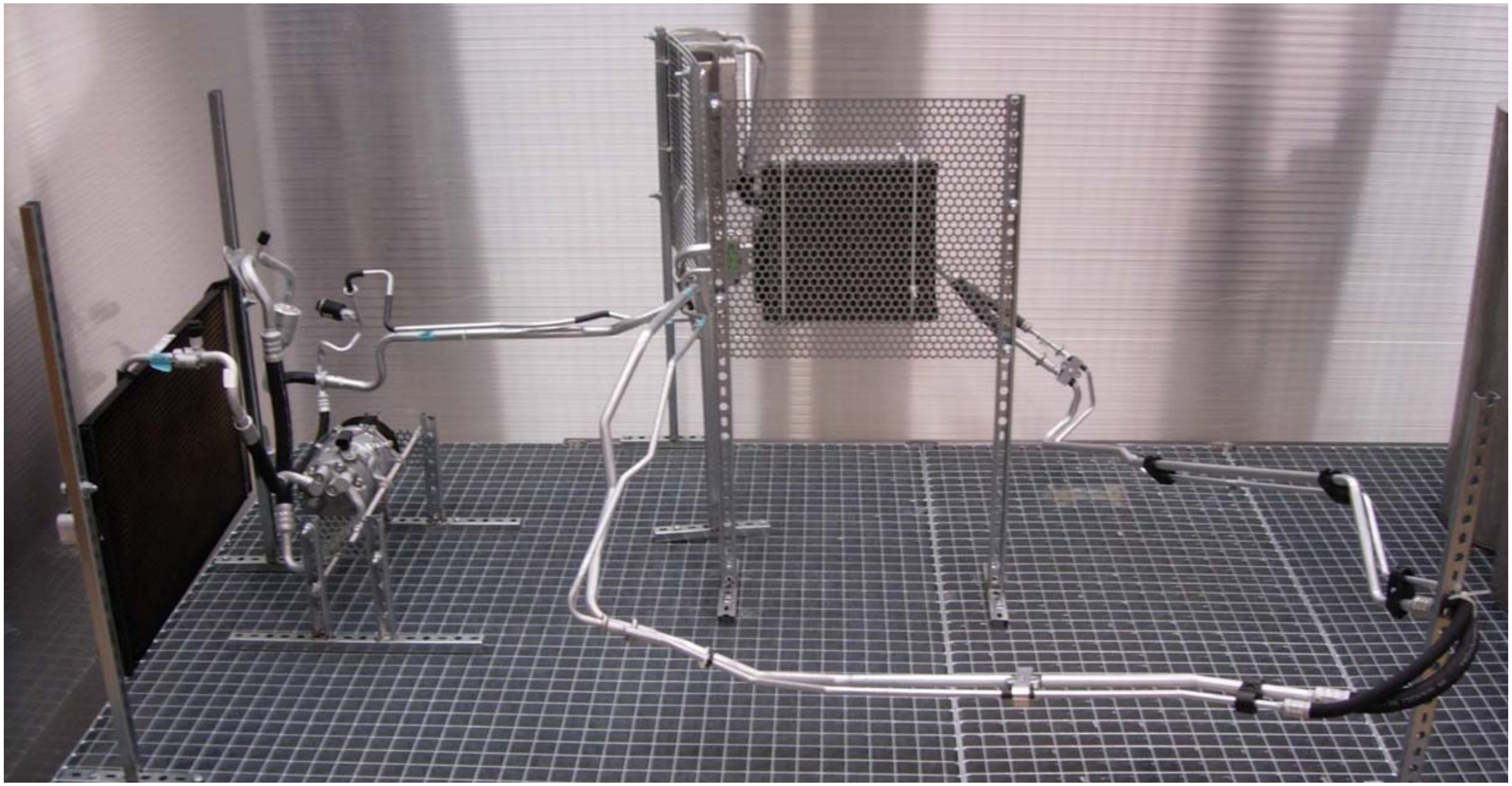
Principle

- The component or the AC system is installed in an accumulation volume or a mini shed at atmospheric pressure with reconstituted air
- The component or the AC system is set under R-134a pressure (by heating)
- The raise of R-134a concentration inside the accumulation volume or the mini-shed is continuously measured by a gas analyzer.



Tests in laboratory / Preparation of the MAC system

Each AC system is mounted and installed on duckboard, then charged with its original refrigerant charge and pre-conditionned during 10 days at 50°C.

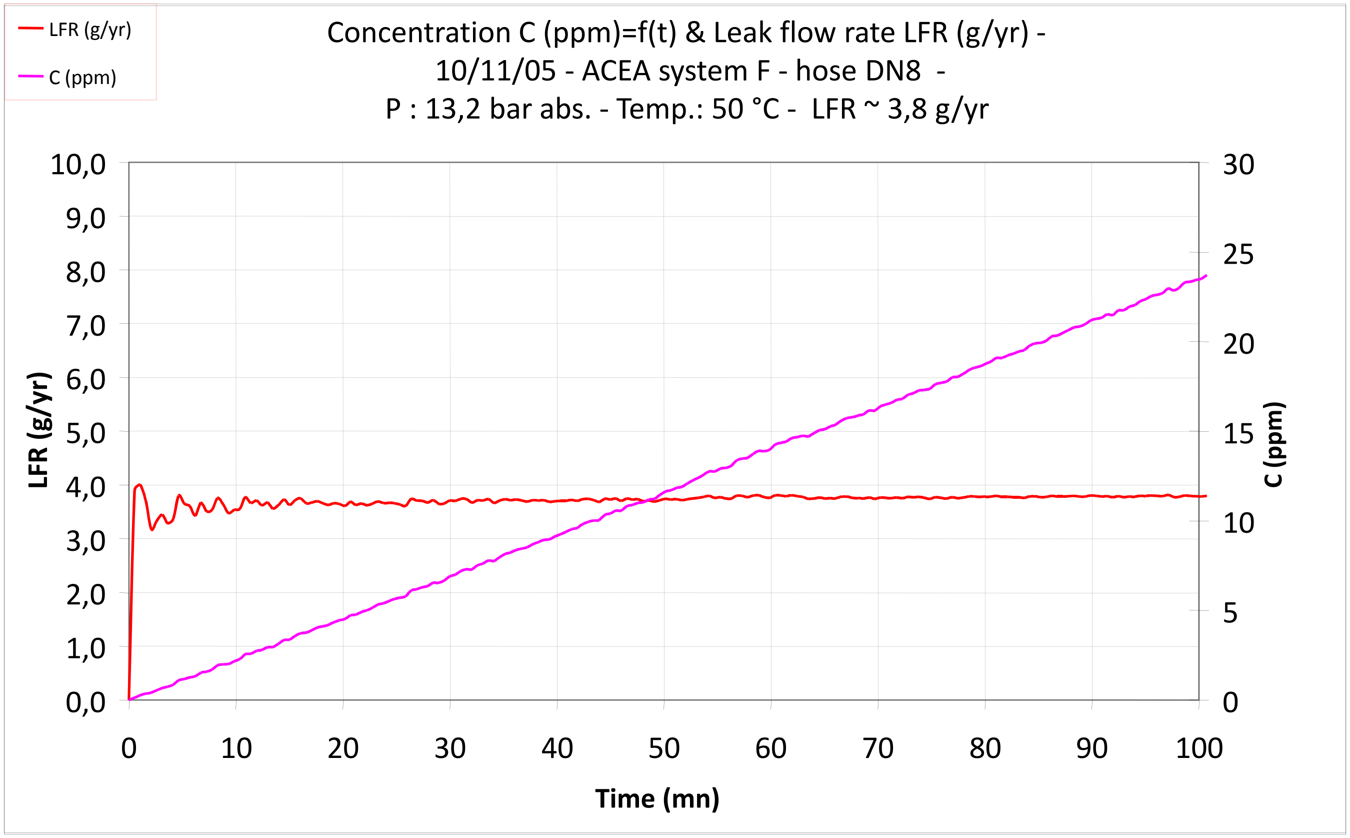


Tests in laboratory / MAC systems in mini-sheds

- MAC systems are installed inside tight mini-sheds at atmospheric pressure.
- Tests are performed at 3 different saturating pressures.

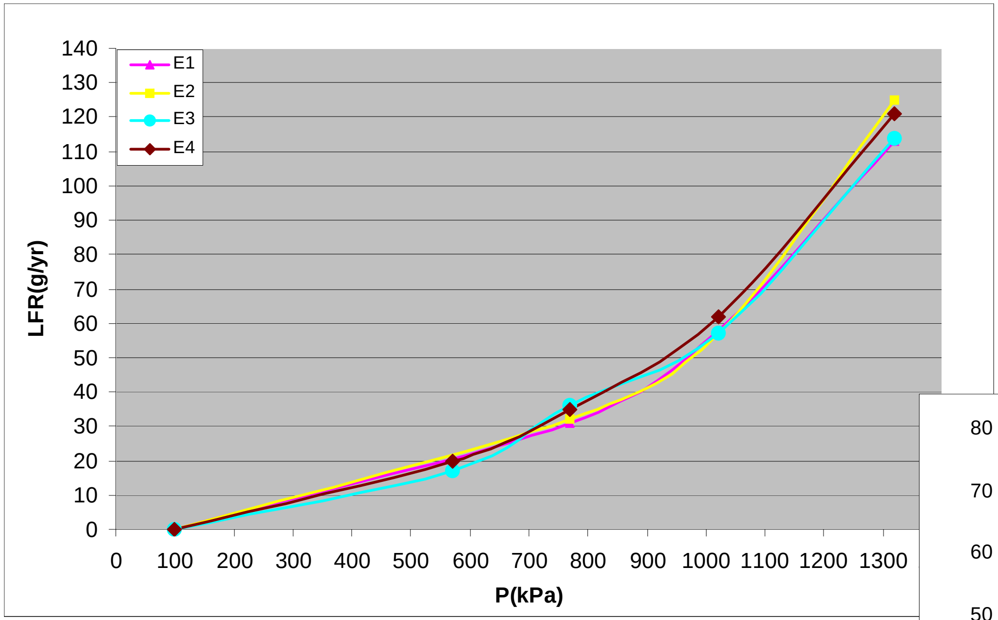
Tests in laboratory / Measurements results : The system LFR

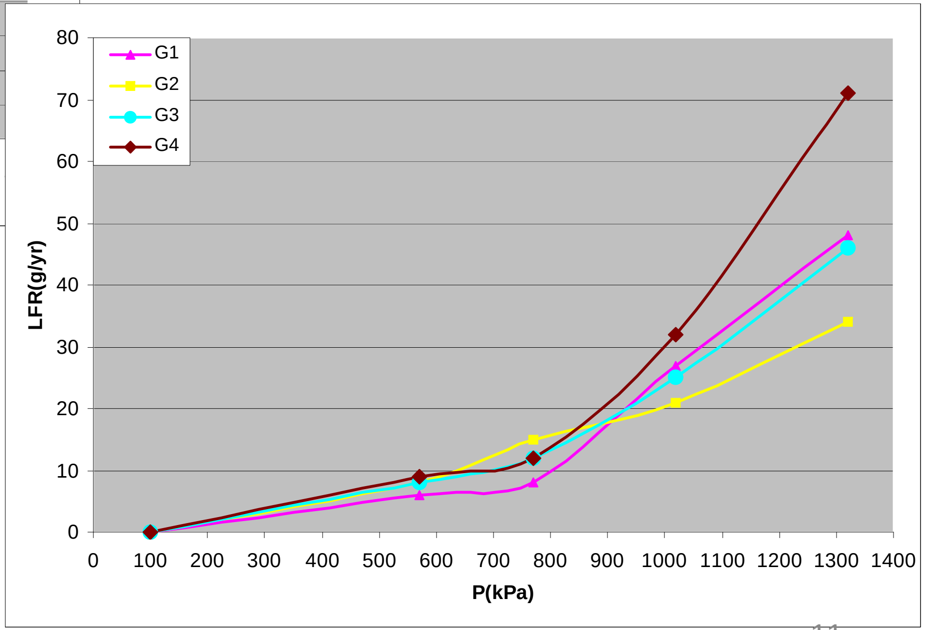
Several hundreds of concentration measurements for a unique result: **the Molar Flow Rate (ppm) => Leak Flow Rate (g/yr)**



Tests in laboratory / Measurements results: The system LFR

Leak flow rates of the system





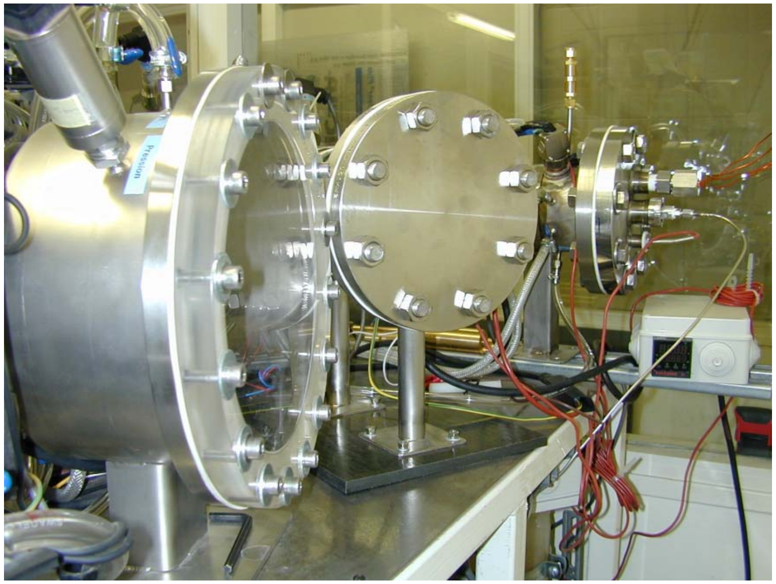
Tests in laboratory / Measurements results: The system LFR

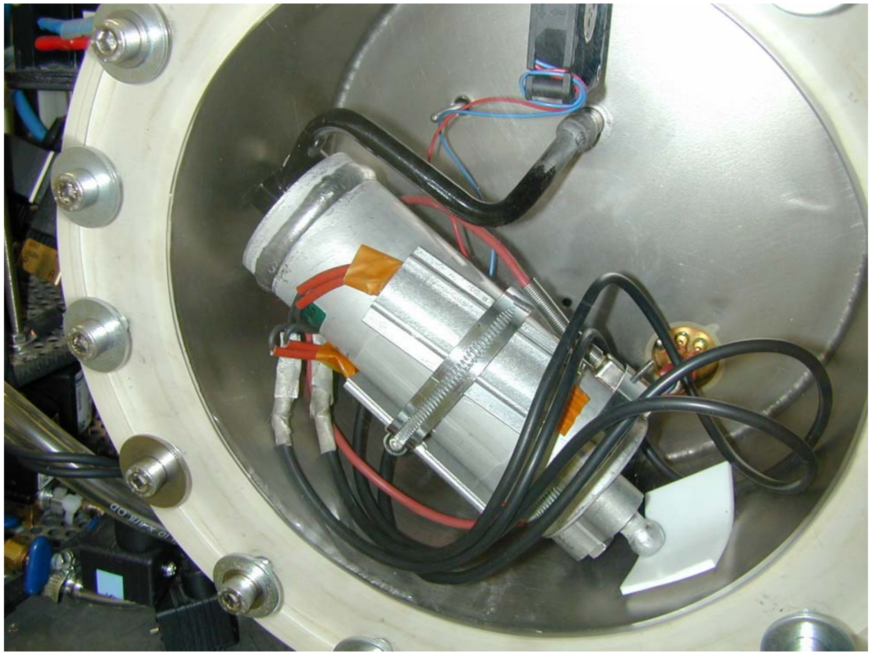
Leak flow rates of the system

	Leak flow rates (g/s)		
Temperature (°C)	**30**	**40**	**50**
System			
A	$15.8^{5.2}_{-3.8}$	$34.7^{4.3}_{-3.7}$	67^{9}_{-10}
B	$18.2^{1.8}_{-2.2}$	45^{2}_{-2}	$82.5^{3.5}_{-4.5}$
C	$17.2^{4.8}_{-5.5}$	33^{2}_{-3}	$60.6^{6.4}_{-7.6}$
D	$26.5^{17.5}_{-9.5}$	$47.5^{15.5}_{-13.5}$	$87.2^{53.8}_{-33.2}$
E	$33.5^{2.5}_{-2.5}$	$58.5^{3.5}_{-1.5}$	$118.2^{6.8}_{-5.2}$
F	$22.7^{1.3}_{-2.7}$	$33.5^{5.5}_{-6.5}$	$52.7^{6.3}_{-4.7}$
G	$11.7^{3.3}_{-3.7}$	$26.2^{5.8}_{-5.2}$	$49.7^{21.3}_{-15.7}$
H	21^{3}_{-3}	45^{12}_{-8}	$80.2^{14.8}_{-10.2}$
I	$12.1^{1.9}_{-1.1}$	$24.7^{3.3}_{-2.7}$	$41.5^{5.5}_{-3.5}$
J	$12.5^{2.5}_{-1.5}$	$26.2^{0.8}_{-1.2}$	$46.2^{7.7}_{-7.2}$
Average value for the 39 systems	$19.2^{24.8}_{-11.2}$	$37.6^{25.4}_{-16.6}$	$68.8^{72.2}_{-34.8}$

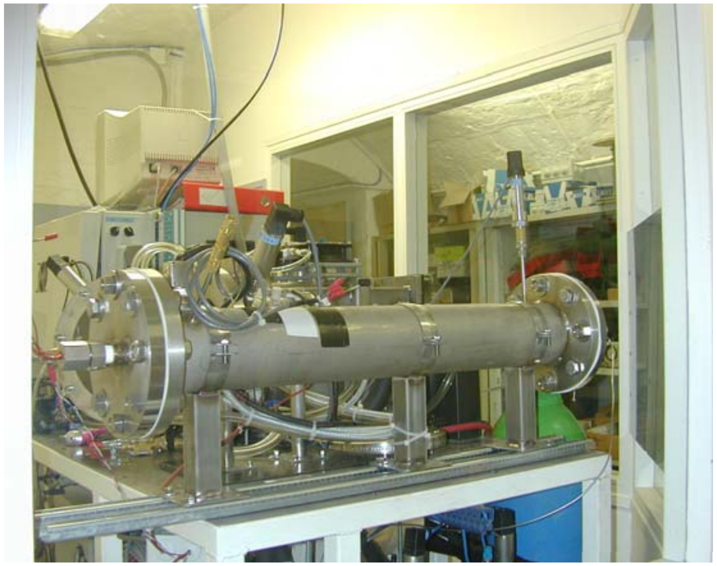
Tests in laboratory / Measurements of component leak flow rates

Cells for fittings and small components

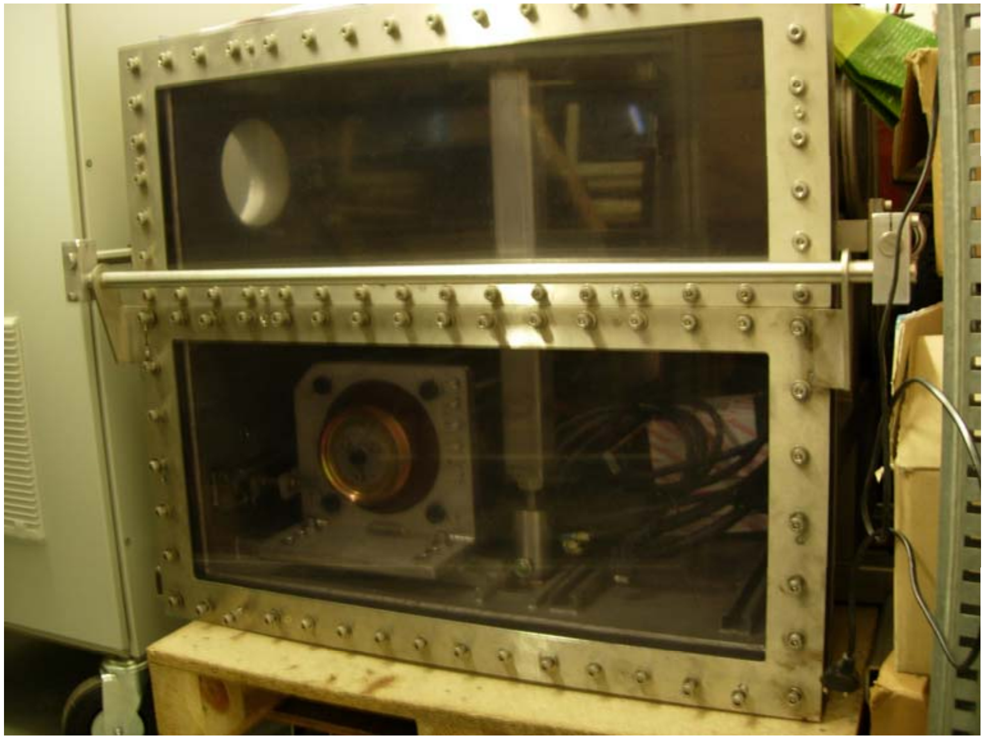




Tests in laboratory / Measurements of component leak flow rates



Cell for hoses and crimps



Cell for compressors

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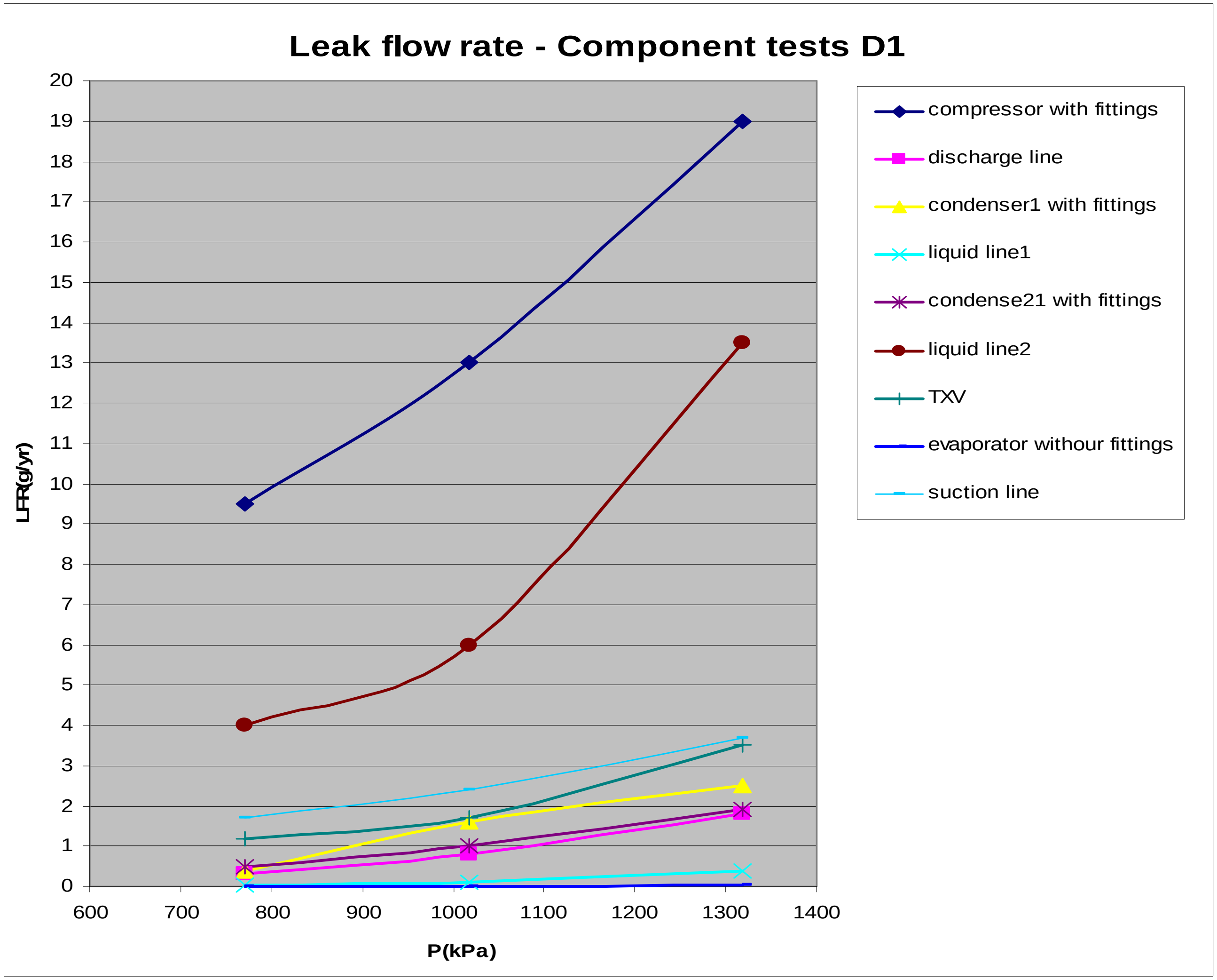
Tests in laboratory / Measurements of component leak flow rates

Tests results



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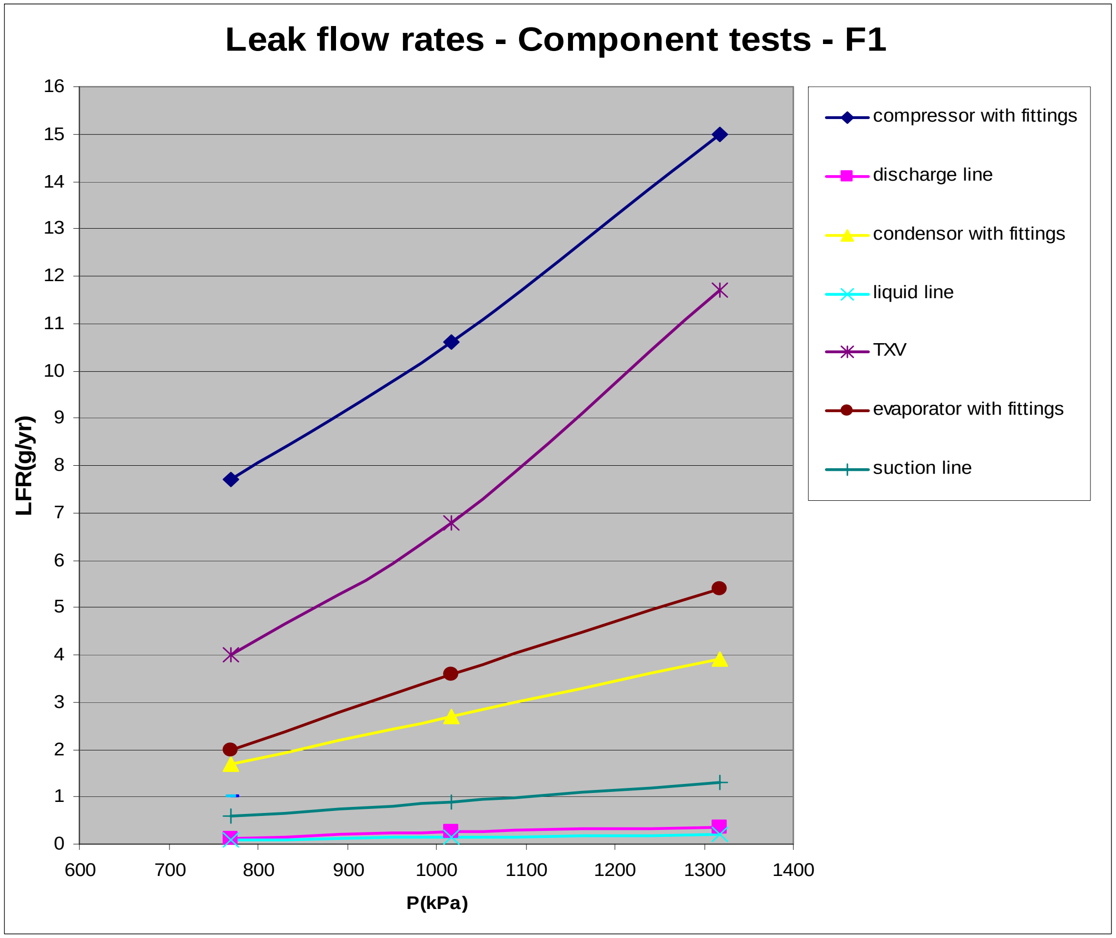
Tests in laboratory / Measurements of component leak flow rates

Tests results

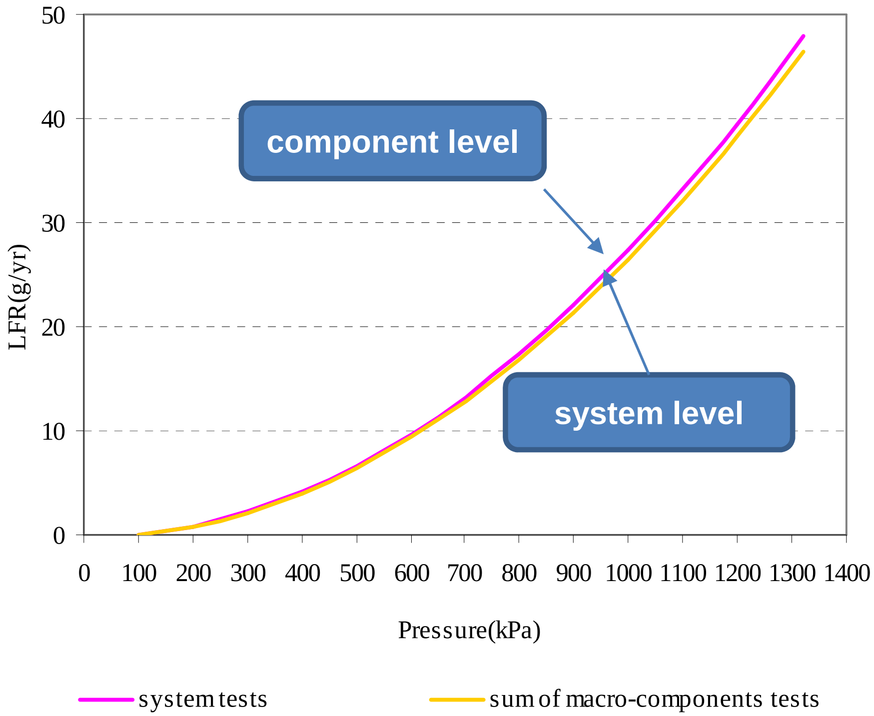


Compressor contribution:
50 to 60%

MAC compressor is the major responsible for HFC-134a emissions

Tests in laboratory / Comparison of component LFRs and system LFRs

Average LFRs of all 39 systems (red curve) and average LFRs of all 103 components (yellow curve) are very close providing that testing conditions (preconditioning, delay between pre-conditioning and tests) are identical.



Tests in laboratory / Measurements results / Correlation factor

- Behavior law can be derived from the tests of systems and components. Results of tests are consistent with leaks in viscous regime and with permeation through elastomer. Even if detailed correlations may be developed specifically for components, the behavior of systems can be represented by a correlation integrating the main physical phenomenon: the dependency of the LFR from the refrigerant pressure.

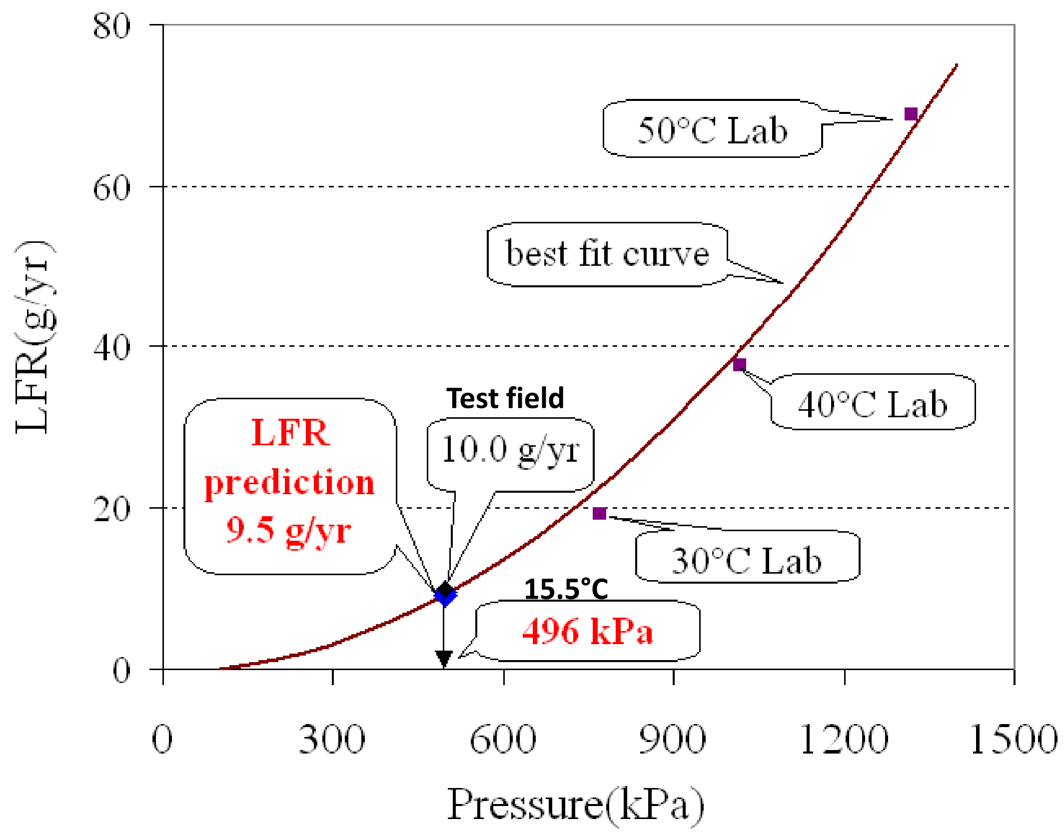
$$ALFR = C\left(P_{upstream}^{2} - P_{downstream}^{2}\right)$$

Pupstream	R-134a pressure in the system or the component
Pdownstream	test chamber pressure (atmospheric pressure)
C	a factor integrating all specific parameters of each component or system

This equation allows to calculate the Annual LFR (ALFR) based on climatic conditions and field test values.

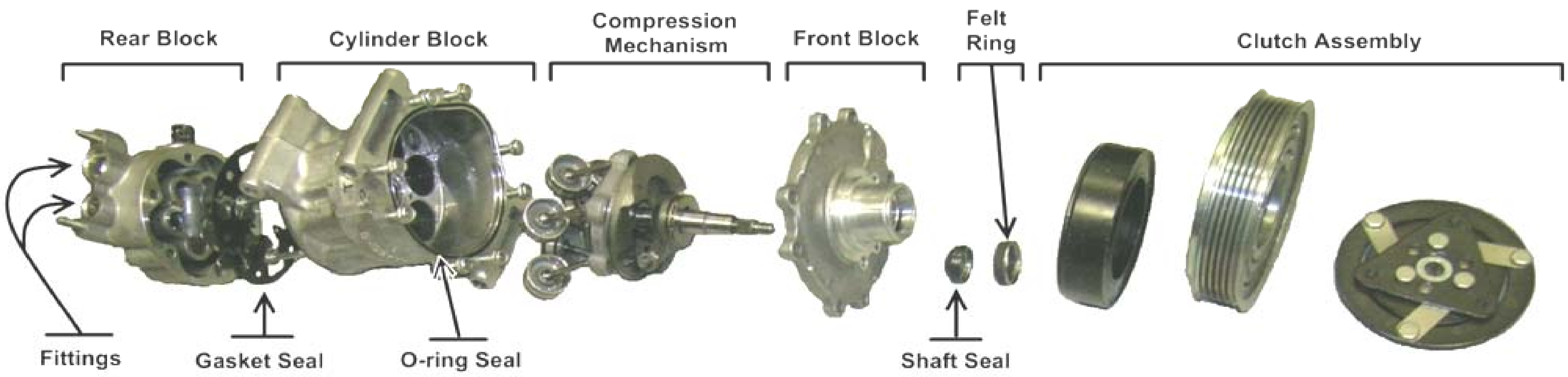
Tests in laboratory / Measurements results / Correlation factor

Taking into account the regression curve integrating the laboratory test results on the 39 systems, and results of the fleet tests on the 37 vehicles, it is possible to correlate the laboratory tests at any given temperature referred to the average annual emission of the fleet.



The compressor – Open type - Belt driven by the vehicle engine

Compressor is **at rest 95 to 98%** of its lifetime



The compressor - Leak tightness degradation [SOU08]*

- **New** shaft seal contribution

	Average LFR@1020 kPa (g/yr)	Shaft seal contribution
24 comp. models	14.0	**50%**
5 shaft seal models	7.0	

- **Aged** shaft seal contribution

Compressor I.D.	Compressor LFR (g/yr)	Shaft Seal LFR (g/yr)	Shaft seal contribution
C1 (1997)	96.6	90.3	**93%**
B1 (new - aged at laboratory)	36.0	25.7	**71%**

Compressor aging destroys the shaft sealing system

➡ Leak tightness degradation with age

* D. SOUSA - Study of refrigerant emissions from mobile air conditioning compressor shaft , Ph. D; Thesis Mines-Paristech, December 2008

MAC systems - Leak tightness degradation [SAB09]*

- The initial low leak flow rates observed for old and new developed MAC systems => no need for servicing

  - Servicing occurs **at least once** during the vehicle lifetime
  - High HFC-134a consumption for servicing not matching with demand obtained from RIEP when applying observed initial leak flow rates

⇒ Leak tightness degradation of MAC systems confirmed

- Use of an inverse model based on double top-down (refrigerant sales declarations /bottom-up (equipment) approach: initial LFR for old technologies **doubles** as off age 6

* [SAB09] SABA, S. - Global inventories and direct emission estimations of greenhouse gases of refrigeration systems, Ph. D; Thesis Mines-Paristech December 2009.

MAC systems- Leak tightness degradation [SAB09]

MAC systems

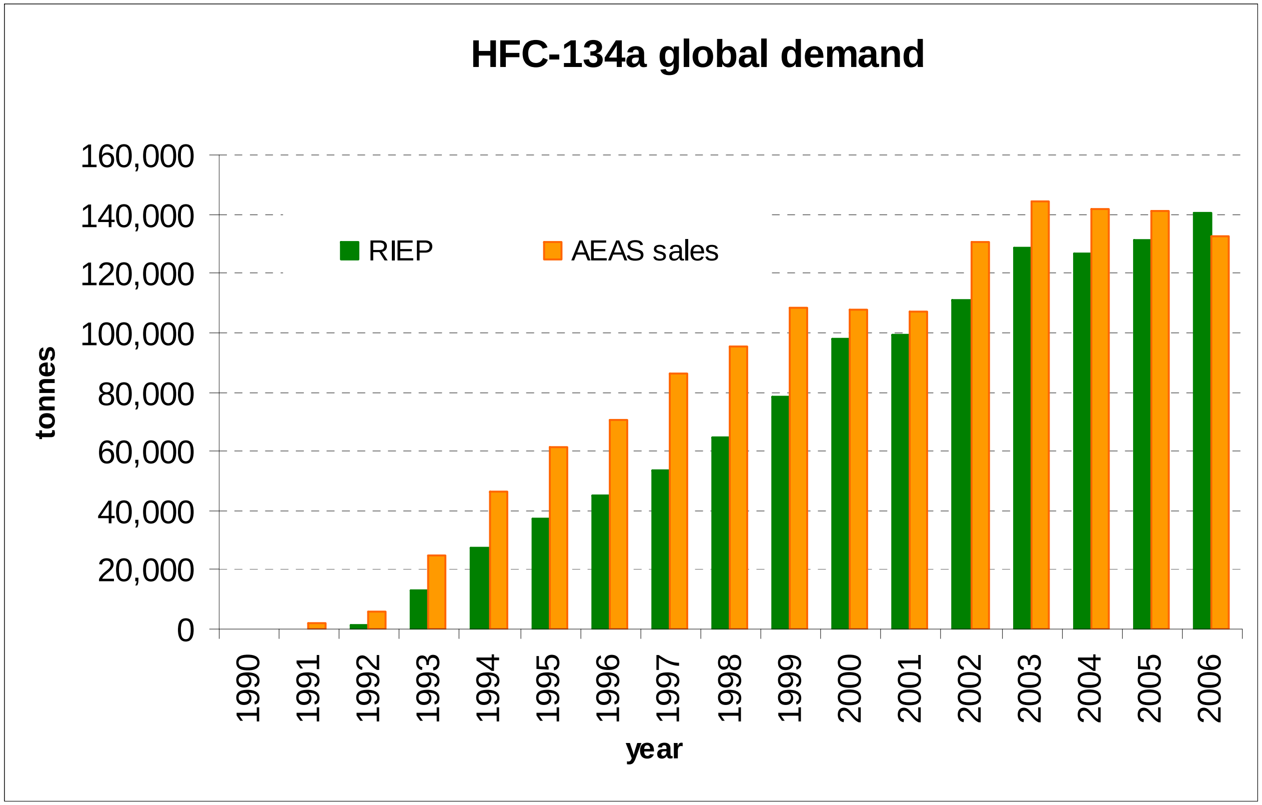
Domestic refrigerators

Centrifugal chillers

Standalone equipment in commercial refrigeration

Stationary air conditioning

Industrial refrigeration



17% difference on the cumulative sales for the period 1990 to 2006

AFEAS (Alternative Fluorocarbons Environmental Acceptability Study)

Sources of emissions from MAC systems/ Conclusions

- Average leak flow rate from new MAC systems: 10g/yr

- The results have shown that the sum of LRFs of components equals the LFRs of the AC systems providing that test conditions are identical.

- Real life conditions and laboratory tests can be correlated by correlation factors

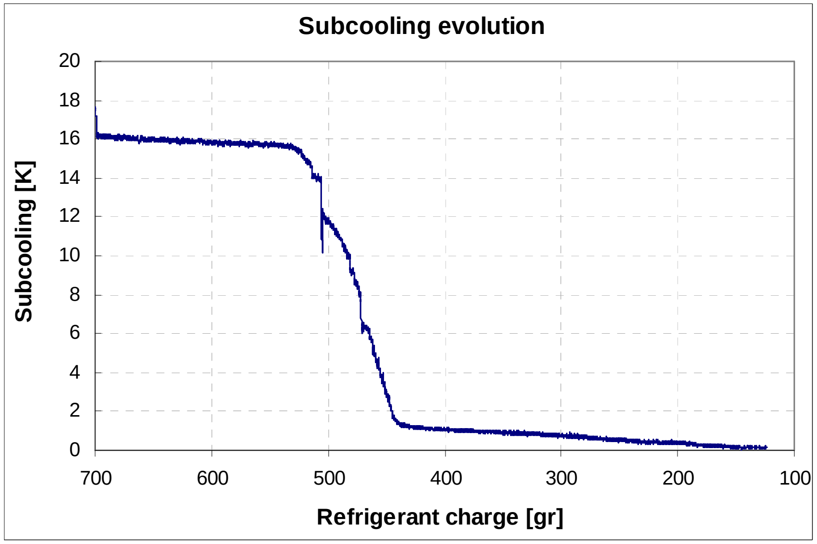
- Compressor is the main source of HFC-134a emissions

- Compressor shaft seal degradation with age increases emissions

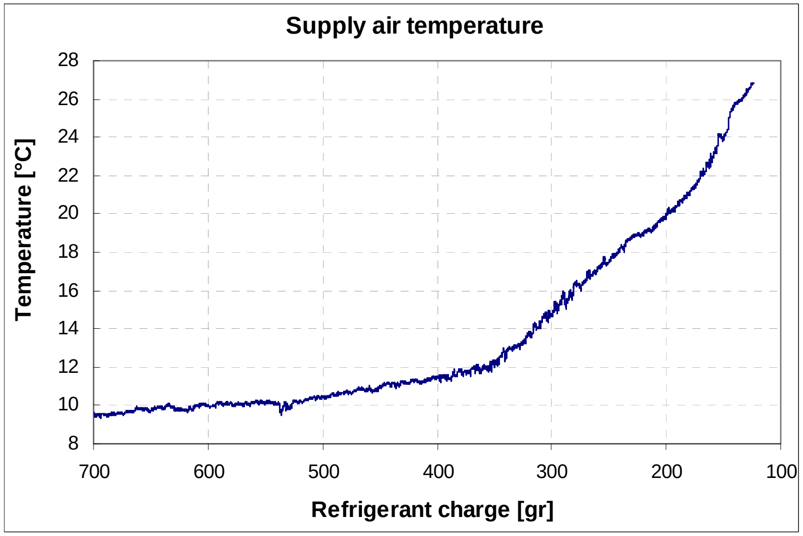
Servicing of MAC systems

Cooling capacity and refrigerant charge

Sub-cooling temperature evolution



Blown air temperature evolution



Laboratory tests / Emission characteristics of small cans [TRE08]*

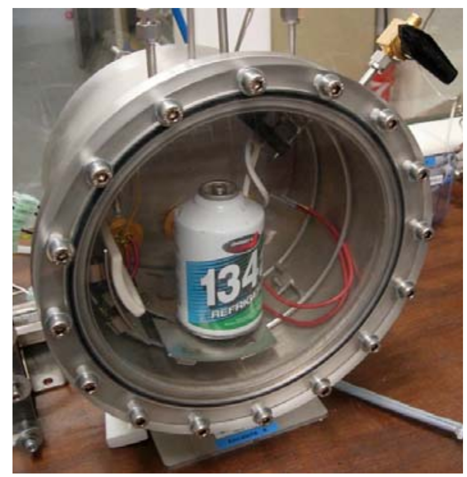
Self-closing valve small cans

Screwed and perforated small cans

- Experimental setup

  The can is installed in an hermetical volume

  - The rise of refrigerant concentration is measured by and infrared spectrophotometer
  - Uncertainty = 6%

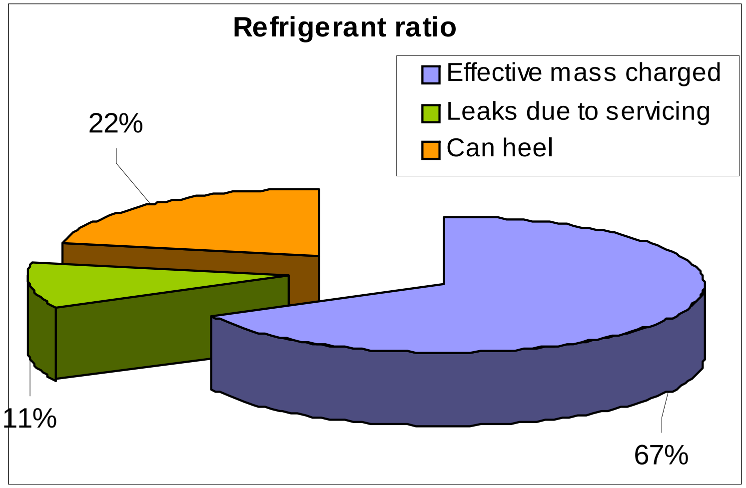


Cell volume

* TREMOULET, Arnaud, RIACHI, Youssef, SOUSA, David, PALANDRE, Lionel and CLODIC, Denis. Evaluation of the Potential Impact of Emissions of HFC-134 From Non Professional Servicing of Motor Vehicle Air Conditioning Systems. Final report for CARB, july 2008.

Lessons learnt from the studied sample of Diyers

- Small cans emissions are linked with the charging kit
- Emissions depend less on the type of container



2/3 of the refrigerant has been charged in the MAC system, 1/3 has been emitted.

Issues with non-professional servicing :

•Recharge without knowledge of remaining refrigerant and of the reference charge

•Recharge without leak search

•Recharge without recovery

•Wrong recommendations written on the can or the pressure gauge of the charging kit

Lessons learnt from the studied sample of professionals

Service practices :

- The technician releases the refrigerant to the atmosphere, evacuates the system and recharges it

- The technician recovers the refrigerant, recycles it with an automatic machine, evacuates the system, and recharges it partially or completely

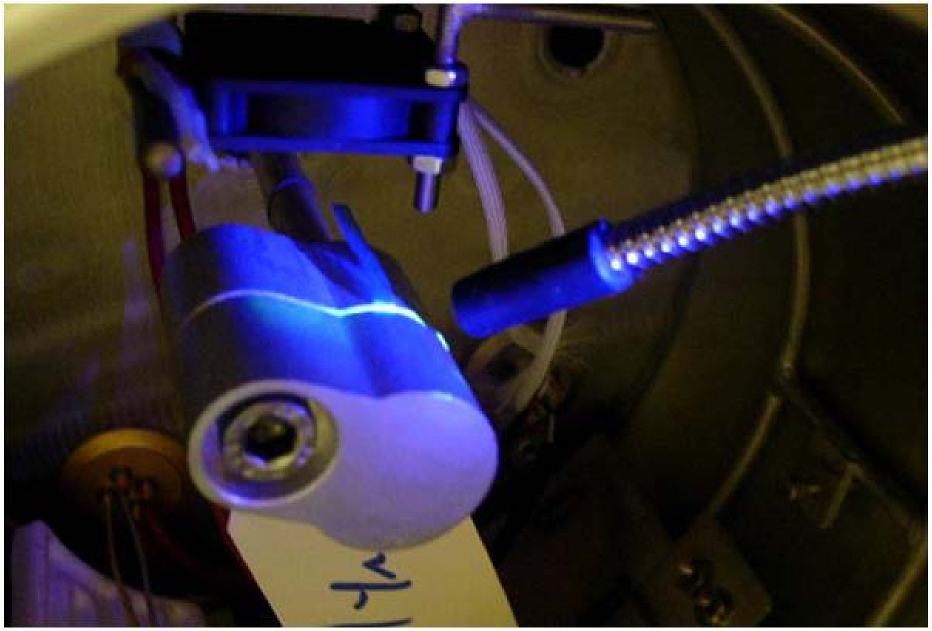
- The technician keeps the system untouched with the remaining charge

- The technician adds refrigerant to the remaining charge

Leak search and sensitivity of leak search methods

Visualization by UV lamp of florescent dye

Verification of sensitivity of ELD



Leak search and sensitivity of leak search methods

2nd leak test - Lubricated contact				
Test method / Sample	IS [g/yr] (Infrared Spectrophotometer)	ELD (Electronic Leak Detector)	SB (Soap Bubbles)	DYE [hr] (Fluorescent leak detector DYE)
No.1	14.7	Not detected	Not detected	3
No.2	120	Detected	Detected**	0.8
No.3	5.7	Not detected	Not detected	11
No.6	0.7	Not detected	Not detected	***
No.4	0.05	Not detected	Not detected	*
No.5	0.05	Not detected	Not detected	*

Test results : Dye is better than ELD and soap bubbles

Recommendations / Servicing of MAC by non professionals without small cans

Efficient recharge of MAC system with small can requires more skills than the use of an automated RRR machine

What is needed to lower emissions for professional and non professional servicing ?

- For leak detection : dye since the manufacturing process for (P) and (NP)

- UV lamp to be rented for (NP)

- Recovery machine weighing the recovered refrigerant available for rental (NP) and in garages (P)

- Fixing efficiently the leak is the duty of professional