Analyses and comparisons of leak flow rates of MAC components and systems

The ACEA study

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CONTENTS

- Accurate measurement of refrigerant losses on a fleet of 40 vehicles
- Accurate measurement of Leak Flow Rates (LFRs) of 40 MAC systems
- Accurate measurement of Leak Flow Rates of more than 100 MAC components
- Correlation factor: from the laboratory test to the fleet emission

AN ACCURATE RECOVERY METHOD

- A sample of 40 (4 x 10) vehicles has been chosen by ACEA.
- The recovery process has been validated on the 10 types of vehicles.
- Initial charge performed within ± 0.5 g precision.
- Recovery 9 months after with a precision of 0 / -1g.

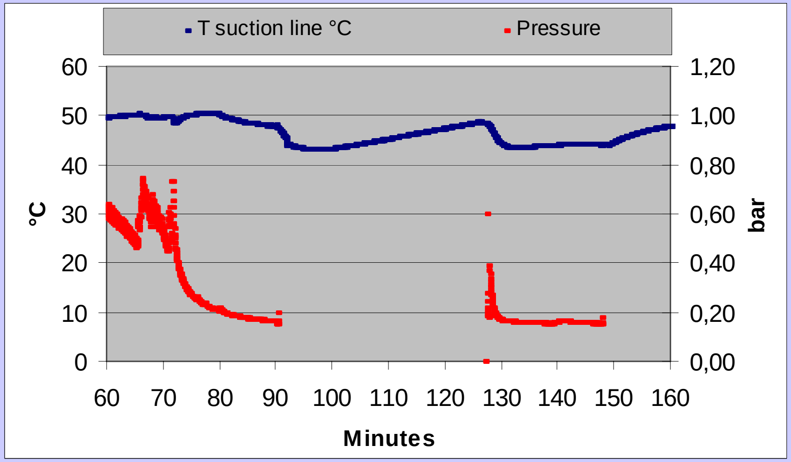
THE RECOVERY and CHARGE PROCESS (1)

- Pre-conditioning of the car 12 hours in the garage at 20°C before recovery
- Heating step 1: running the engine & the AC system to create reference conditions
- Recovery step 1: slow recovery (2 to 10 g/min) recovery of about 98% of the charge
- Heating step 2: heating the engine compartment and the AC system for Refrigerant outgassing

THE RECOVERY and CHARGE PROCESS (2)

- Recovery step 2

After the outgassing, about 1.9% recovered



- Heating step 3 and Recovery step 3

Less than 1g to be recovered or redo Heating and recovery

- Distillation

Separation of R-134a and oil (if any)

- First refrigerant charge

THE RECOVERY and CHARGE PROCESS (3)

- Running the AC system during 30 min.
- Recovery with the same procedure
- Verification that:

  recovered charge = initial charge +0 / -1g

If yes

  Initial refrigerant charge

If no

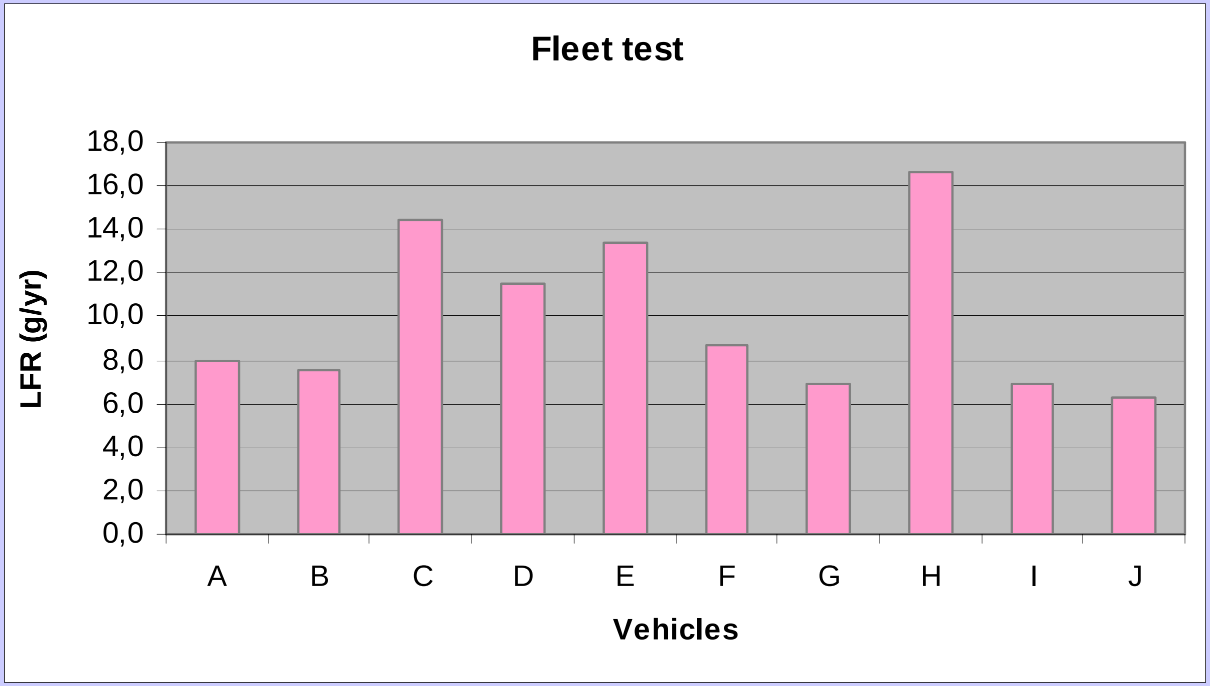
  Redo all the procedure until the precision is demonstrated.

Recovery Document

RECOVERY		☑ LP	☐ HP	☐ LP + HP	
RECOVERY		step 1	step 2	step 3	step 4
	Cylinder initial mass (g)	2602,9			
	Initial mass rec.Equpt.+recovery capacity	**12620,6**	**13219,9**	**13223,4**	
	Beginning Time	12H00	13H30	14H10	
	Ending Time	13H00	13H50	14H20	
	Recovery duration (min)	1H00	20MN	10	
	Total mass rec.Equpt.+recovery capacity	**13219,8**	**13223,4**	**13223,6**	
	Recovered refrigerant mass (g)	**599,2**	**3,5**	**0,2**	
	Pressure at the recovery begin (bar)		**0,3**	**0,165**	
	Pressure at the recovery end (bar)	**0,16**	**0,147**	**0,155**	
	Total Recovered refrigerant mass (g)	**602,9**			
OIL CONTENT	Cylinder mass after distilation (g) under vacuum	2602,9			
	Lubricant mass (g) in the cylinder	0			
	Cylinder +Equip. + lines under vacuum (g)	12621,1			
	total Lubricant mass recovered (g)	0,5			
	Refrigerant recovery - lubricant mass (g)	**602,4**			

The fleet test results

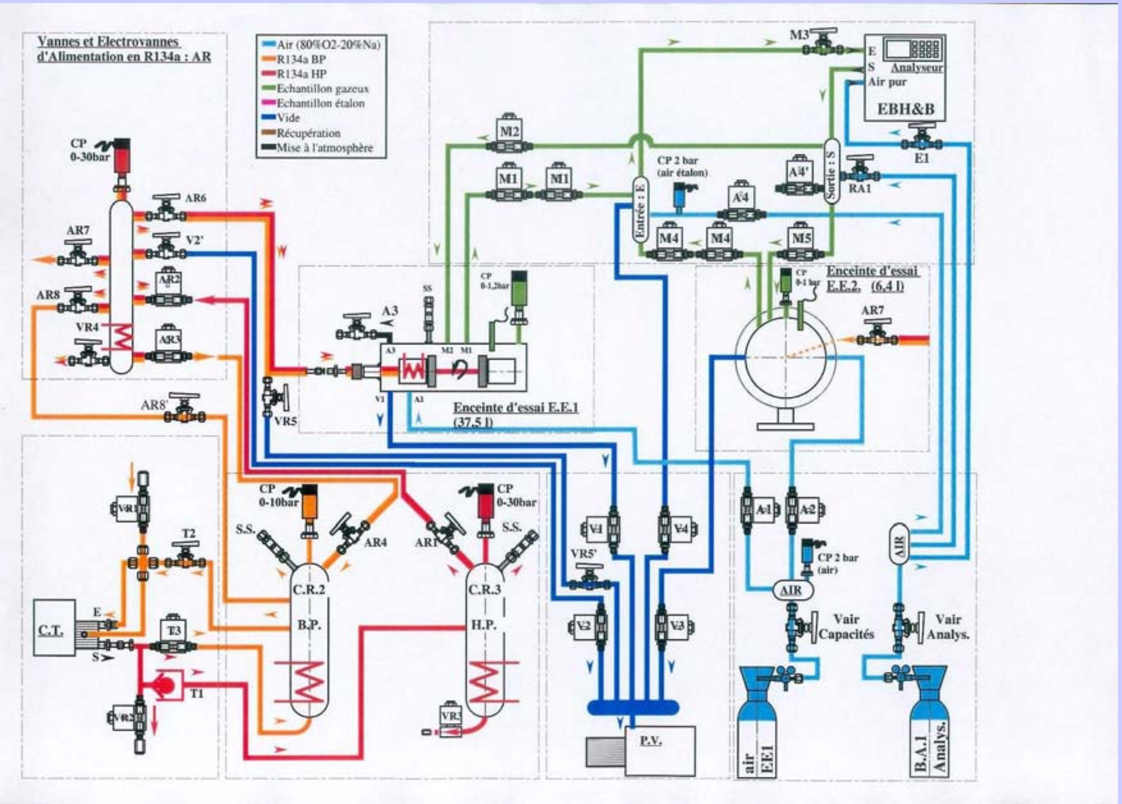
6.3 g/yr < annual emission < 16.6 g/yr
Average emission of the 37 vehicles : 10 g/yr



Accumulation test method

✓ Principle

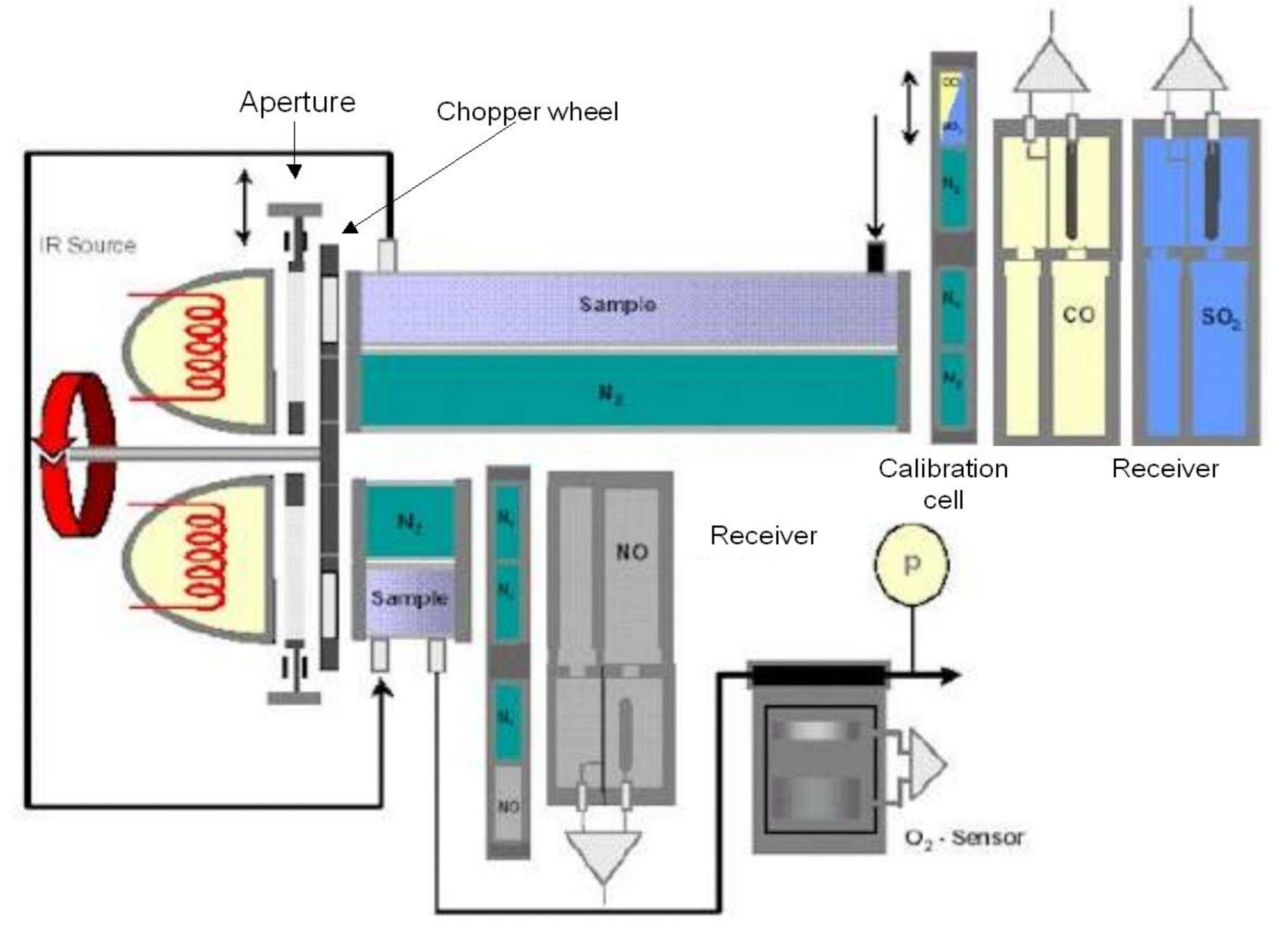
- The component or the AC system is installed in an accumulation volume or a mini shed at atmospheric pressure with reconstituted air
- The component or the AC system is set under R-134a pressure (by heating)
- The raise of R-134a concentration inside the accumulation volume or the mini-shed is continuously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



Measurement apparatuses

IR spectro-photometry

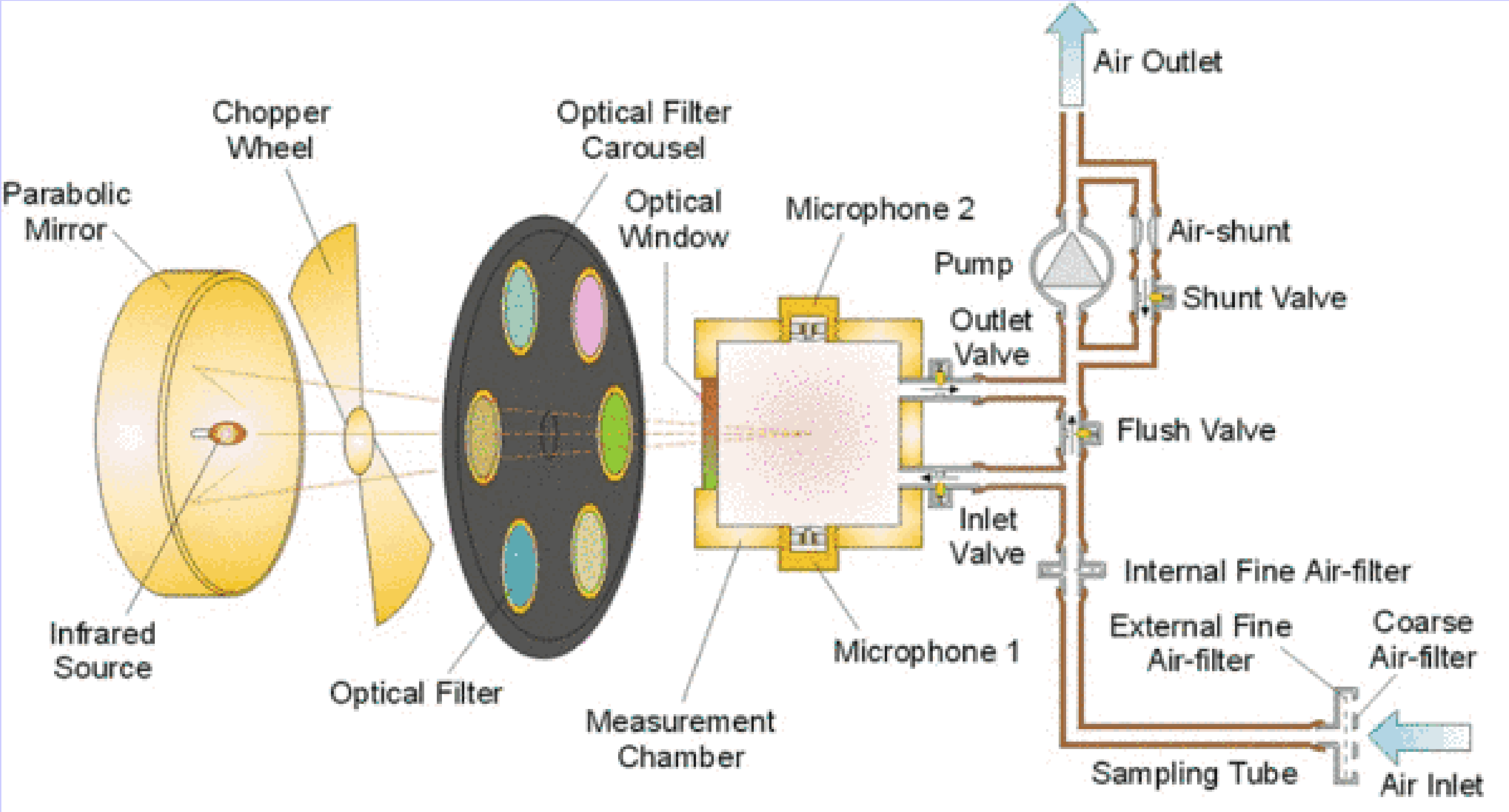
Sensitivity: 0.5 p.p.m



Measurement apparatuses

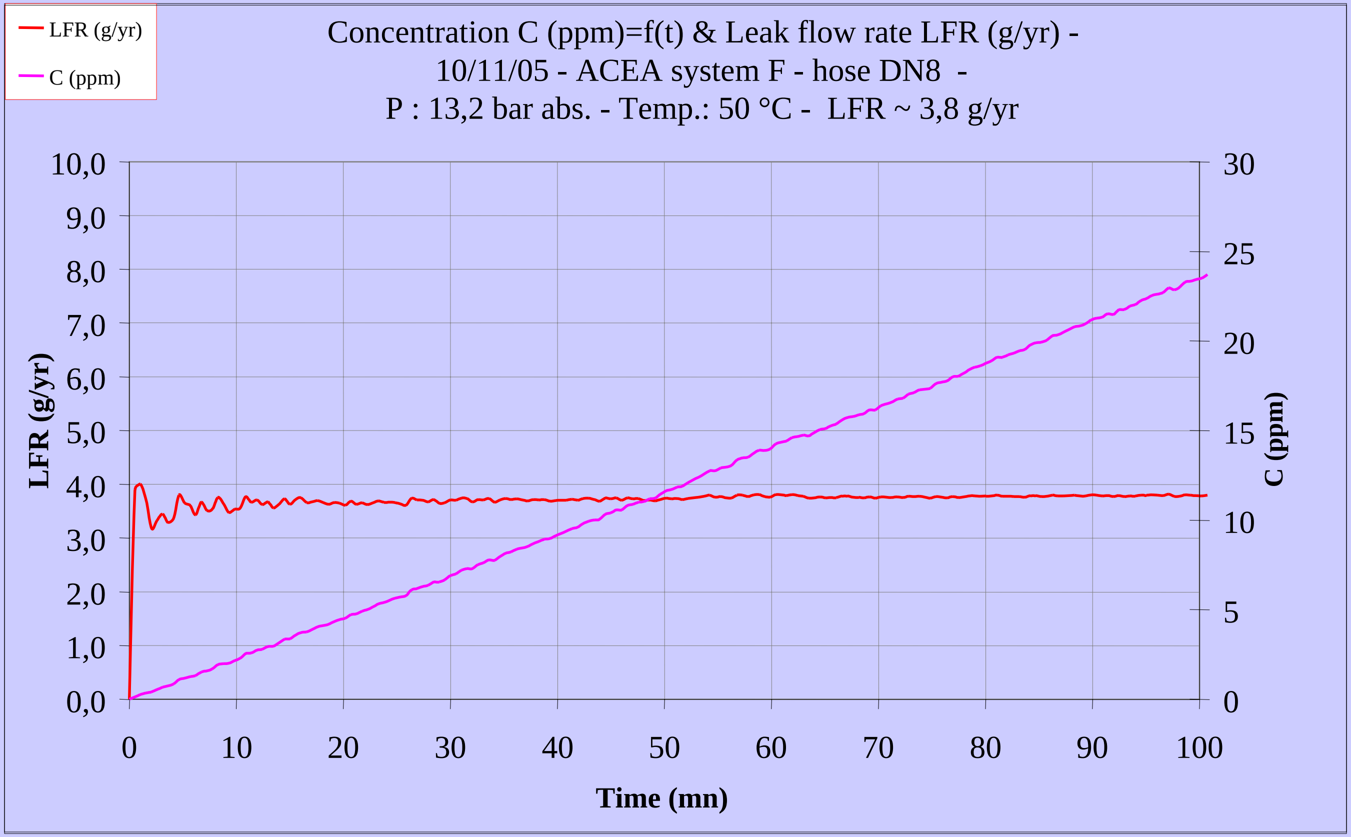
IR photo-acoustics spectroscopy

Sensitivity: 15 p.p.b



Measurement Results

Several hundreds of concentration measurements for a unique result: the molar flow rate.



From Concentration to Leak Flow rate

- The **leak flow rate in steady state** is based on the derivative of the concentration along the time:

$$\dot{N} = \frac{V_{acc}}{V_{mol}} \frac{\partial C_{R-134a}}{\partial t} \qquad (1)$$

- Then the leak flow rate in g/s is calculated:

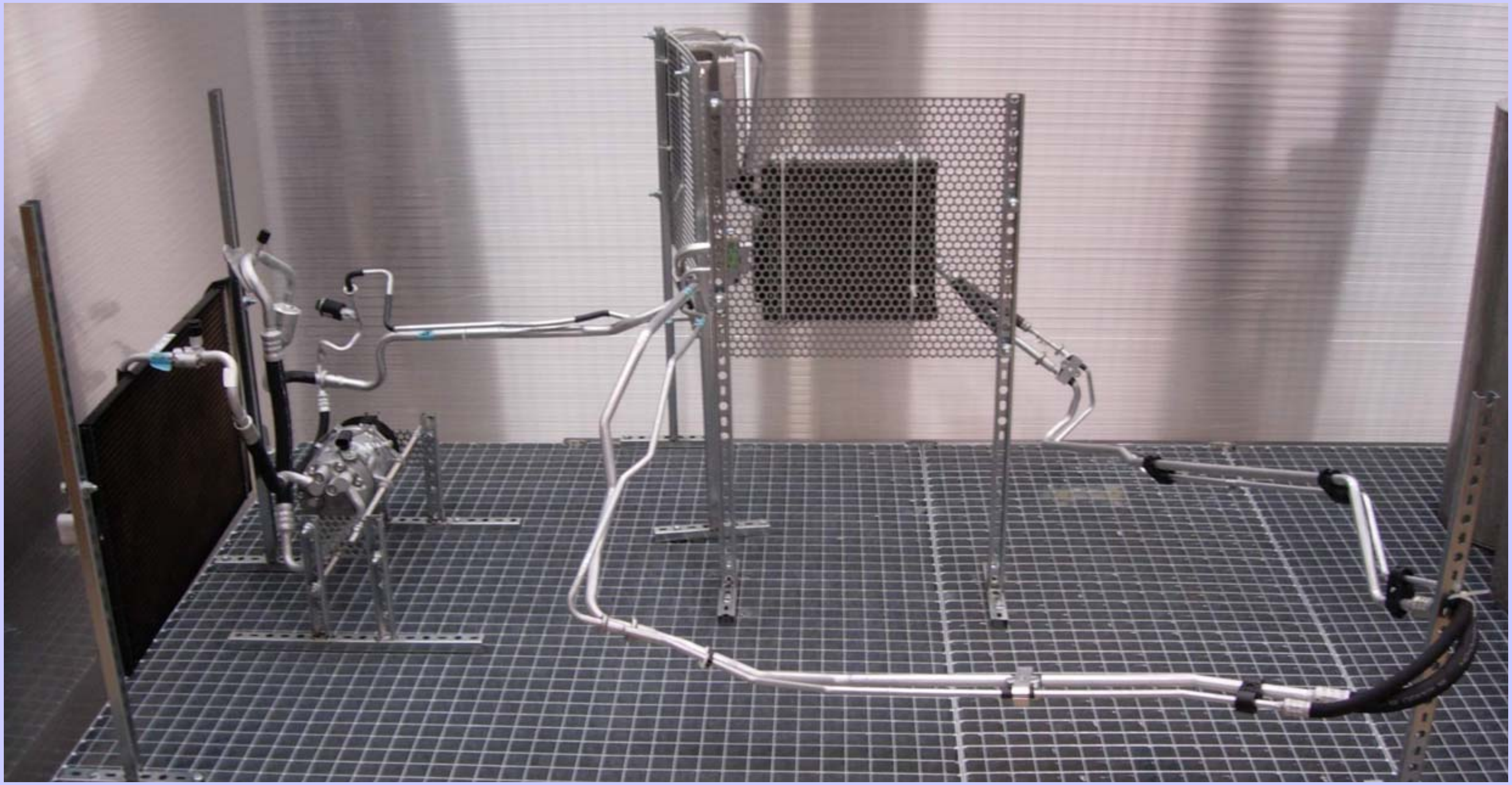
$$\dot{m} = \dot{N} . M \qquad (2)$$

Calibration process

- ✓ Successive steps for the calibration
  - Calculation of the free internal volume of mini-sheds
  - Detailed calculation of all volumes installed in mini-sheds
  - Standardization of the infrared analyzer with standardized gas concentrations
  - Calibration of the calibrated leaks
  - Verification of the concentration measurement inside the mini-shed by the calibrated leak.

Preparation for the 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.

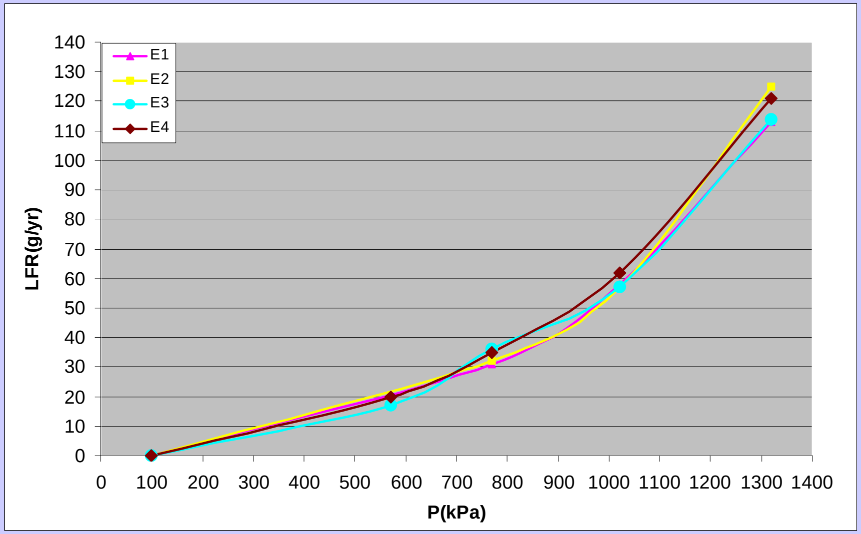


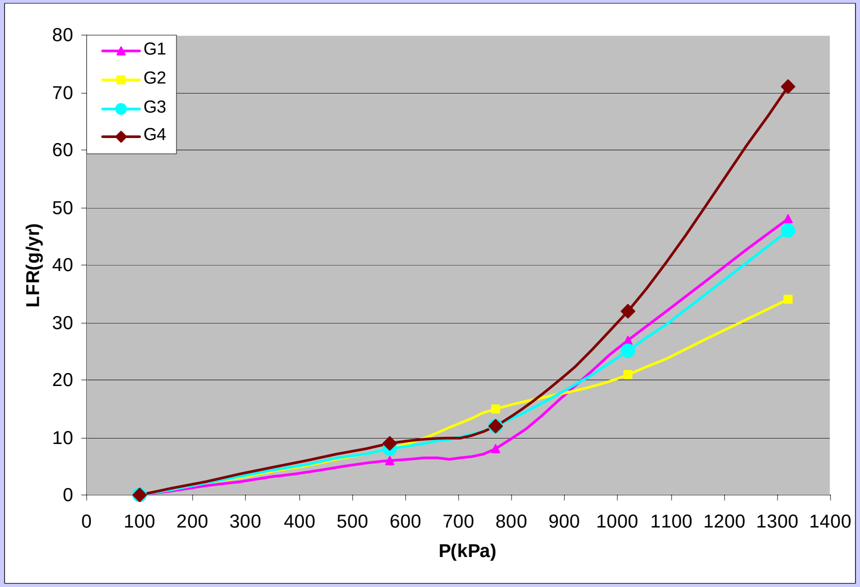
MAC systems in mini-sheds

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

Test results

✓Leak flow rates of systems





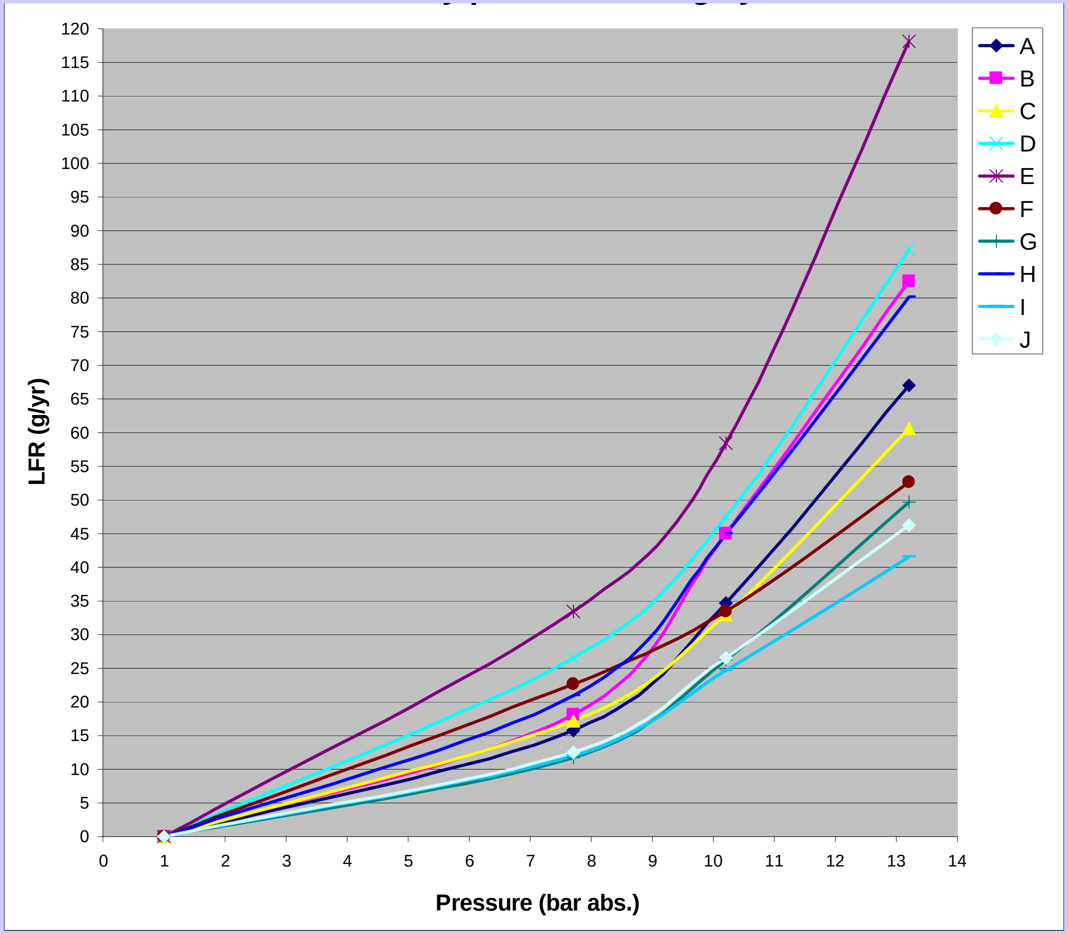
Test results

✓ Leak flow rates of systems

	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	$19.2^{24.8}_{-11.2}$	$37.6^{25.4}_{-16.6}$	$68.8^{72.2}_{-34.8}$

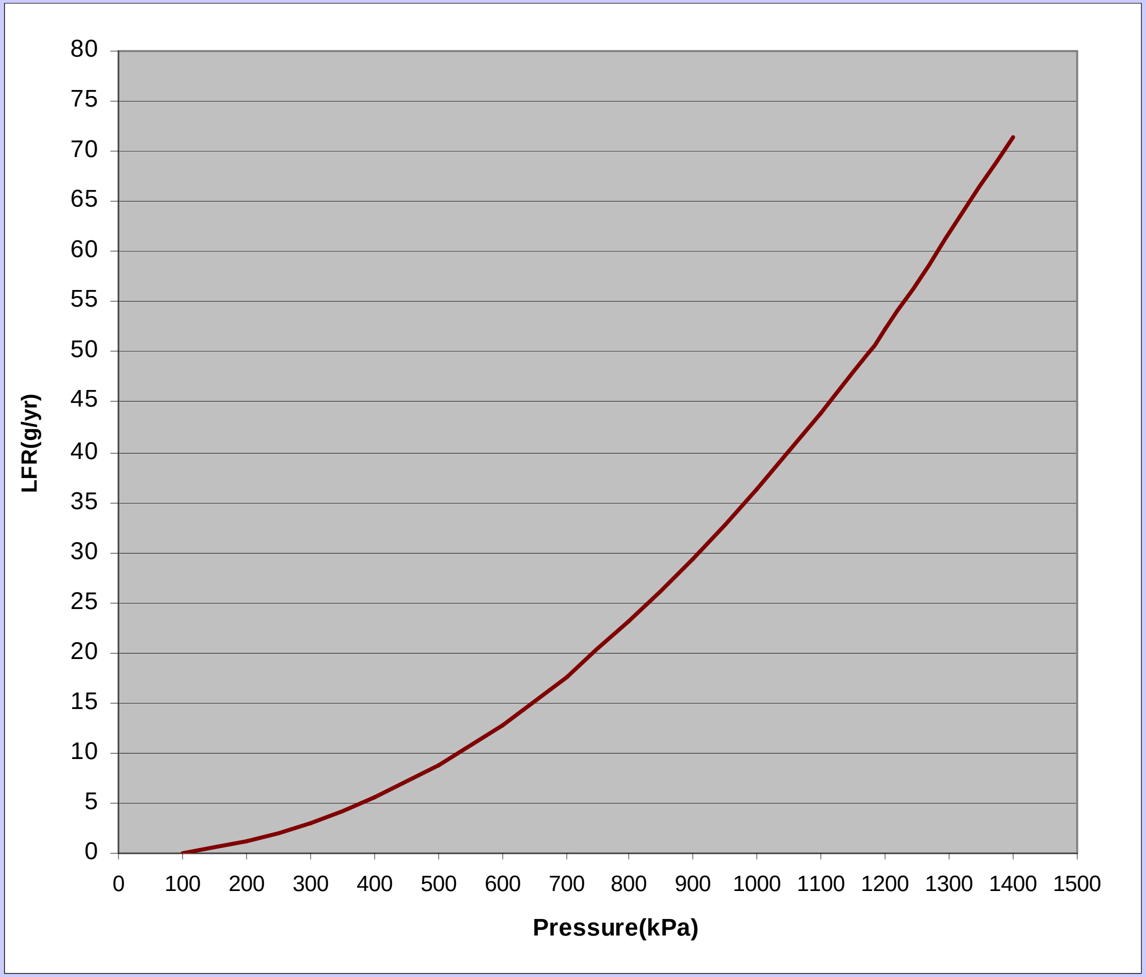
Test results

- ✓Leak flow rates of systems



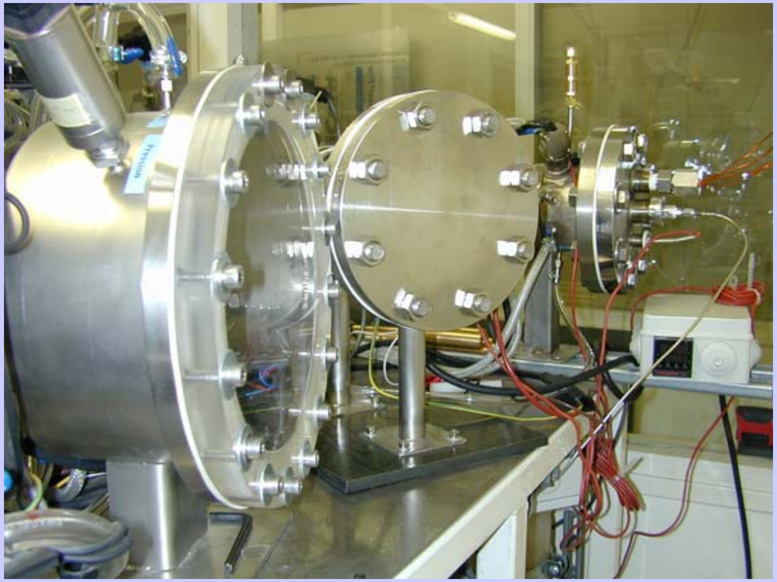
Test results

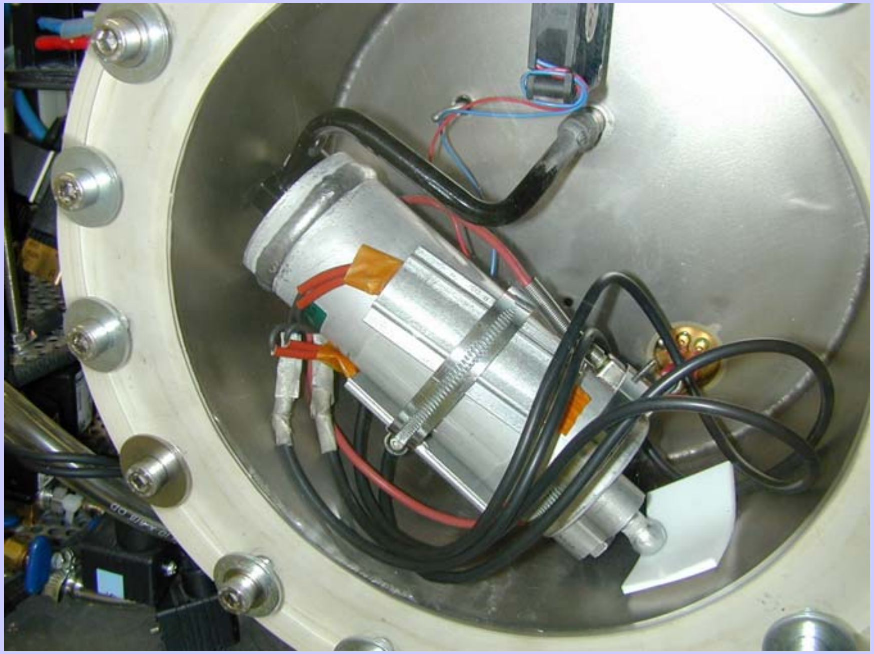
✓ Leak flow rates of systems



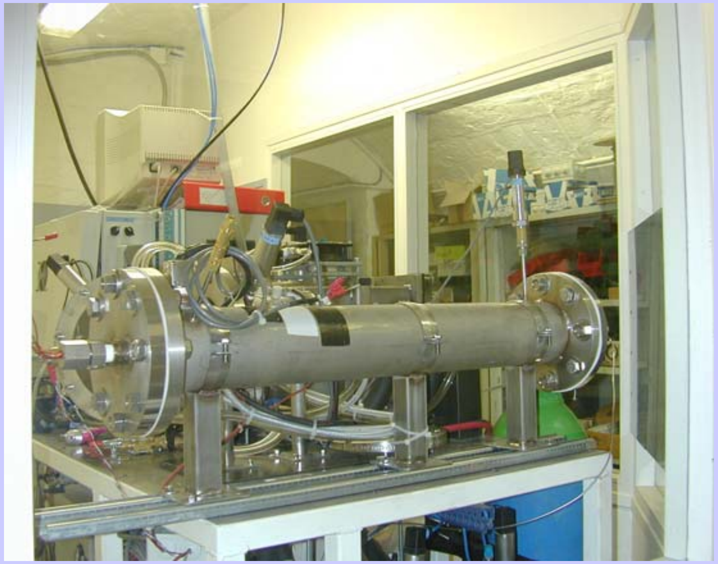
Measurements of component leak flow rates

Cells for fittings and small components

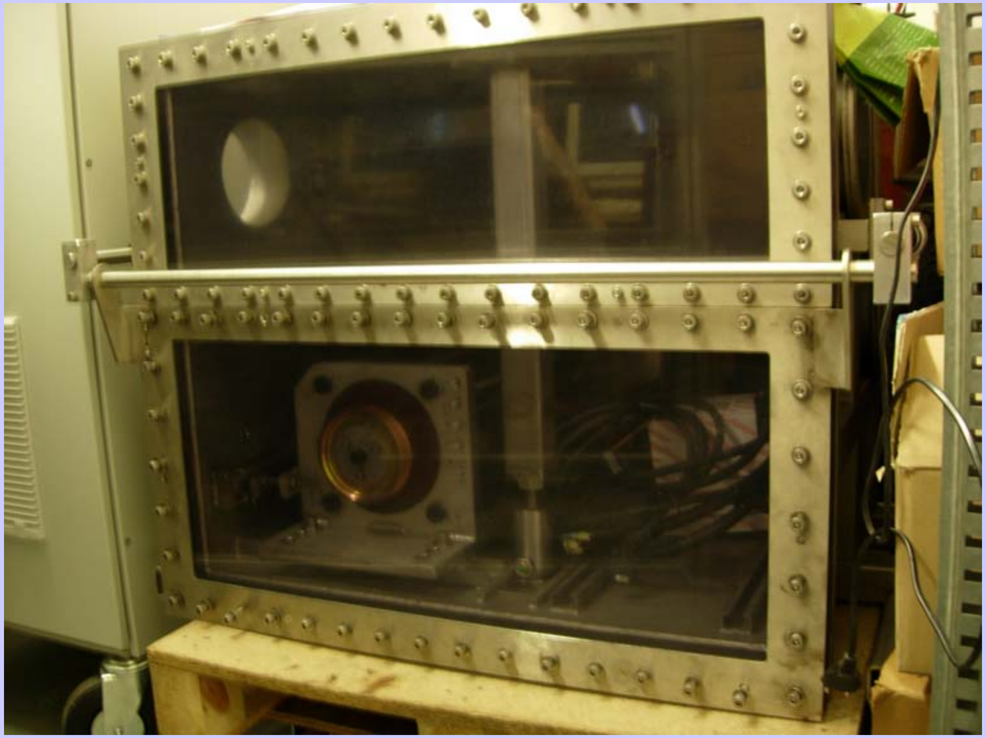




Measurements of component leak flow rates



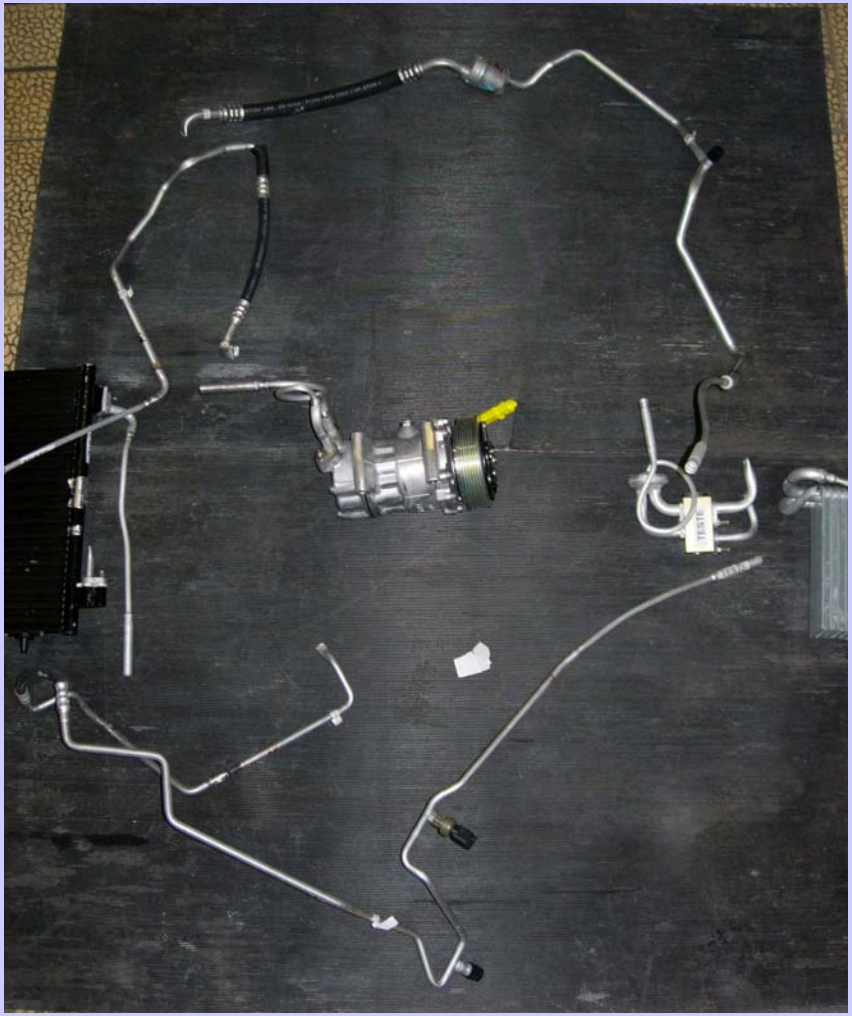
Cell for hoses and crimps



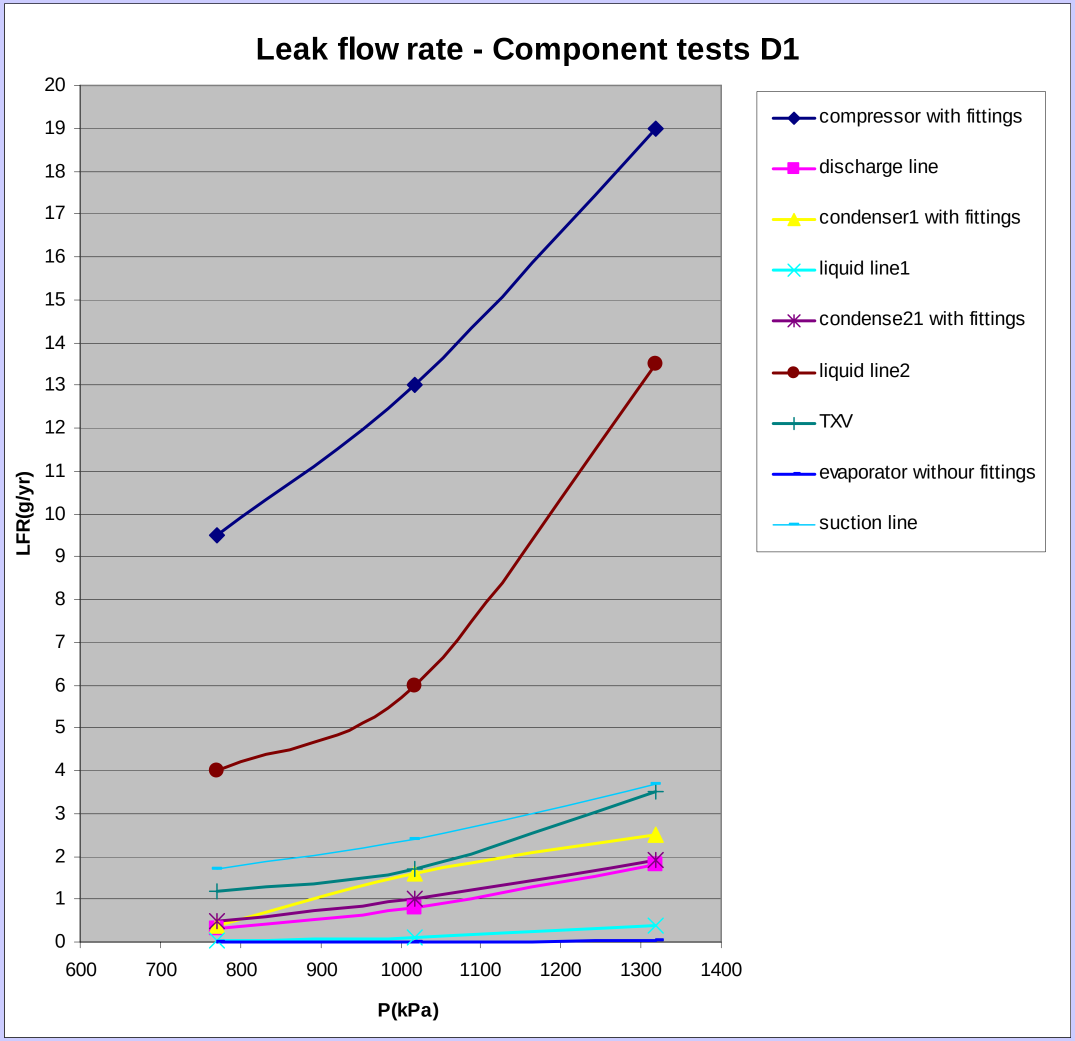
Cell for compressors

MAC components

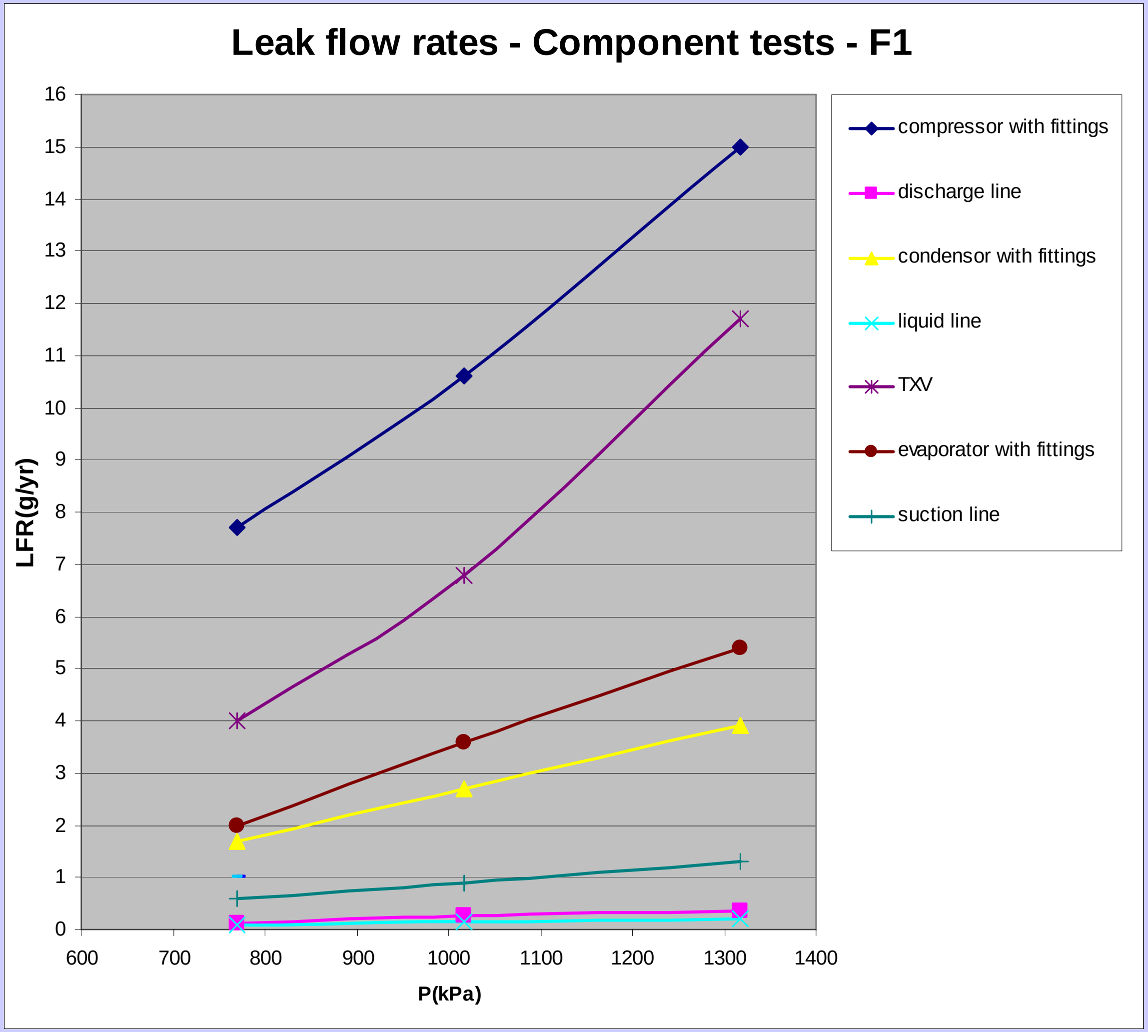
- MAC components cut from previously tested systems under the same testing conditions



Test results

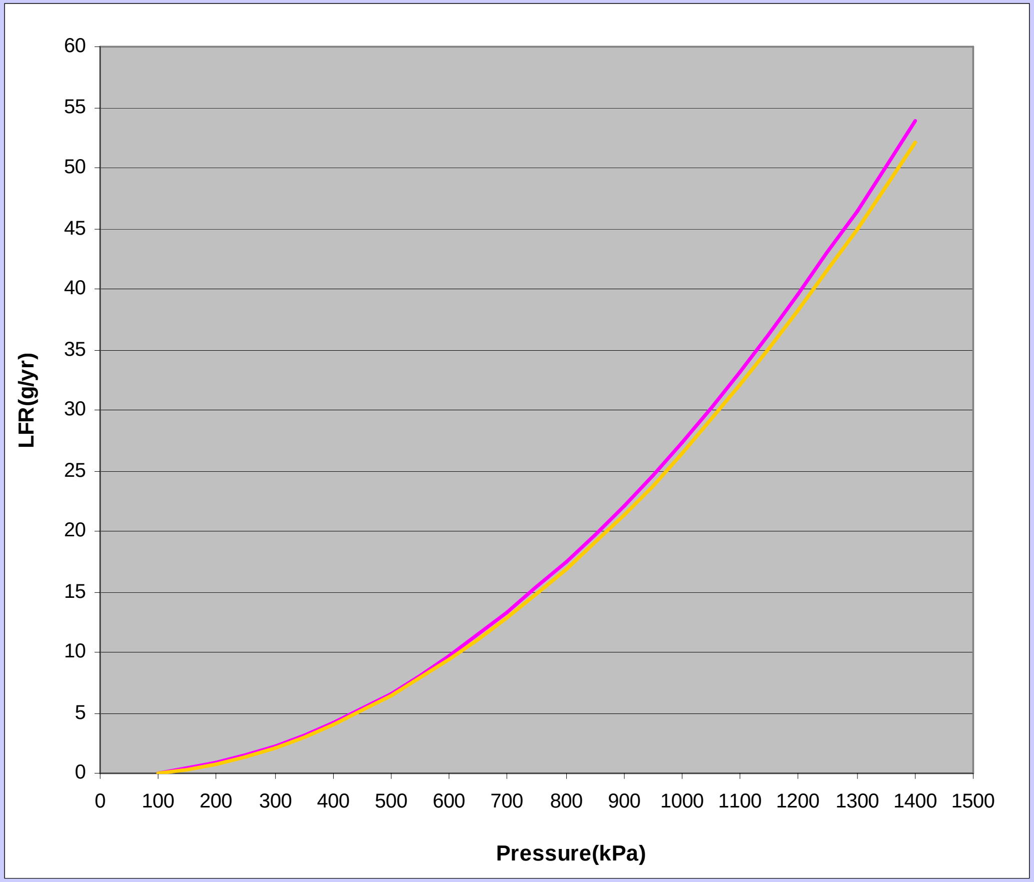


Test results



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.



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.

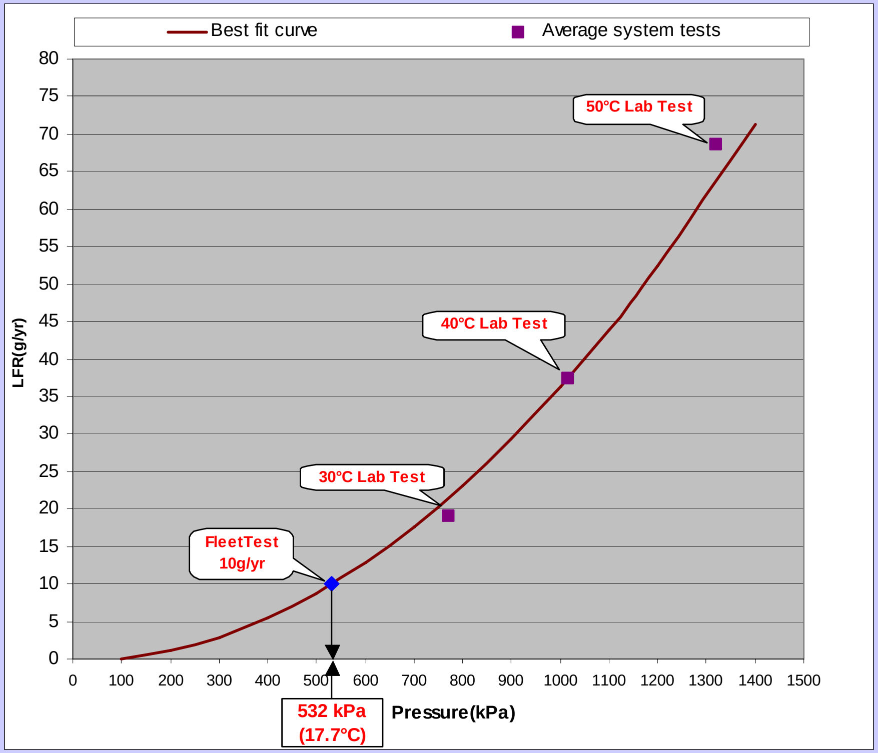
$$ALFR = C\left(P_{upstream}^{2} - P_{downstream}^{2}\right)$$

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.

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.



Conclusions

- ACEA has launched a study in order to demonstrate the possibility of measuring the leak flow rates of AC systems and AC components in laboratory conditions and to correlate those tests to real life conditions.
- Three series of tests have been carried out
  - A fleet test (on 40 vehicles of 10 different types) where the annual leak flow rate has been established by a highly accurate recovery method of the refrigerant charge 9 months after an accurate refrigerant charge
  - Laboratory tests on 40 AC systems (4 x 10 types) identical to the ones of the fleet tests
  - Laboratory tests on components cut from the tested AC systems.

Conclusions

- ✓ The results have shown that the sum of LRFs of components equals the LFRs of the AC systems providing that test conditions are identical.
- ✓ The system tests as well as the component tests show that a behavior law can associate LFRs and the saturating pressure of R-134a.
- ✓ The saturating pressure of R-134a depends on the saturating temperature.
- ✓ The saturating temperature is directly related to climatic conditions (95% of the time the vehicle is in standstill mode).
- ✓ The fleet test has integrated the real life conditions: vibrations, AC operation, engine operation, …
- ✓ For each type of vehicle, the real life emissions are slightly above the predicted value based on the average climatic conditions.
- ✓ Real life conditions and laboratory tests can be correlated by correlation factors.