Refrigerant MAC leakage

New evidences from the Armines /ACEA study

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- ✓ Global emissions from MAC systems
- ✓ Accurate field test measurement and results
- ✓ Method of test for measurment of leak flow rates of systems and components
- ✓ Actual refrigerant charge: consequences on energy performances and servicing
- ✓ Quality control for « no servicing MAC systems »

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Global Perspective of Refrigerant Emissions from MAC Systems

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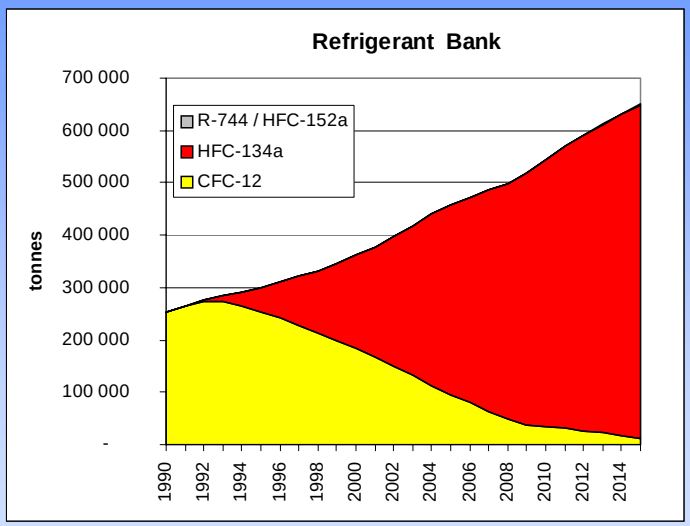
MAC refrigerant bank evolution from 1990 to 2015



[IPCC special Report 2005]

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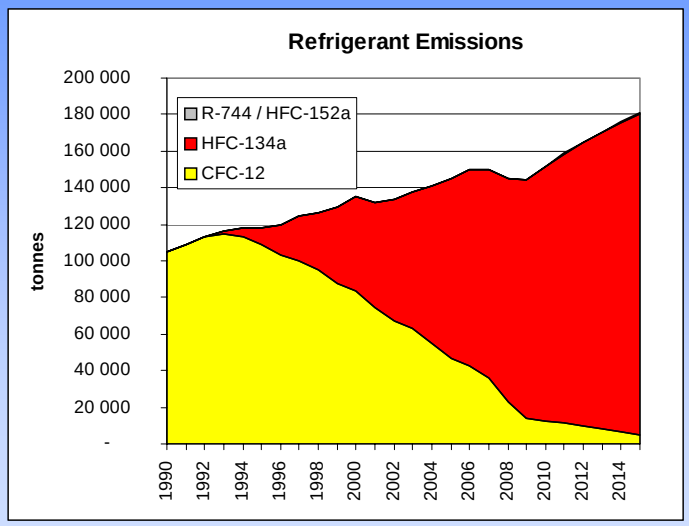
MAC refrigerant emissions from 1990 to 2015



(IPCC Special Report 2005)

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Field test measurements: How to be precise ?

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THE RECOVERY METHOD

From garage method to laboratory method (in garages)

- ✓ A significant sample of vehicles has been defined by ACEA:
  4 samples of 10 different European vehicles
- ✓ The recovery process has been validated for each type of vehicle :
  Initial Recovery in controlled conditions + 1st charge in controlled conditions + 2nd recovery in controlled conditions
- ✓ Results : Is the recovered quantity = the charge quantity within 0 / -1g ?
  Yes: make the charge No: Do it again

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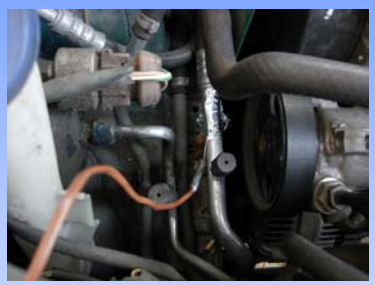
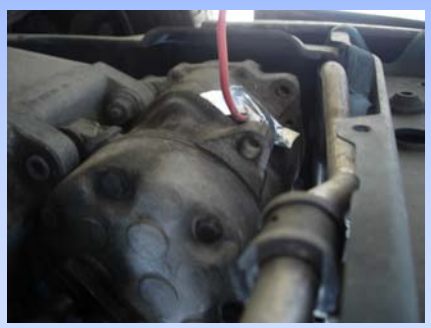
THE RECOVERY PROCESS

Temperature measurements

Suction line temperature



Compressor temperature



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THE RECOVERY PROCESS

- ✓ Recovery system weighing
  - Compressor + hoses + recovery cylinder
  - Precision of the scale: *0.1g*

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Recovery procedure

RECOVERY — ☑ LP ☐ HP ☐ LP + HP

		step 1	step 2	step 3	step 4
RECOVERY	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**

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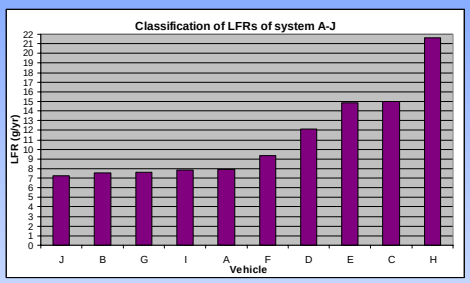
The fleet test results

Vehicle	LFR (g/yr)
J	7,2
B	7,6
G	7,6
I	7,8
A	7,9
F	9,4
D	12,1
E	14,8
C'	15,0
H'	21,6



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Method of test for measurement of leak flow rates of systems and components

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Preparation for the system

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

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MAC systems in mini-sheds

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

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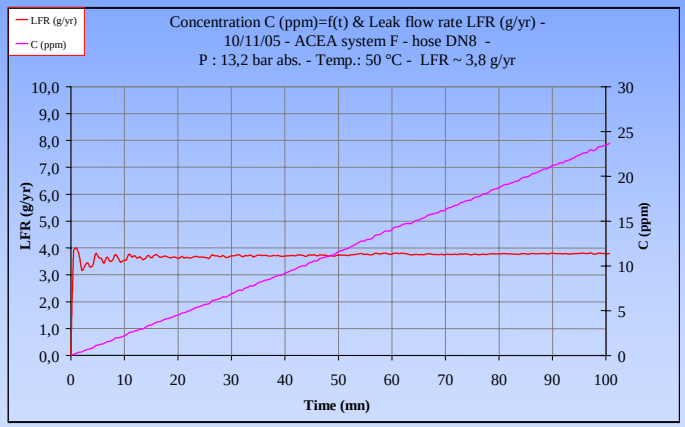
Measurement Results

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



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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:

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

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Measurements of component leak flow rates

Cells for fittings and small components

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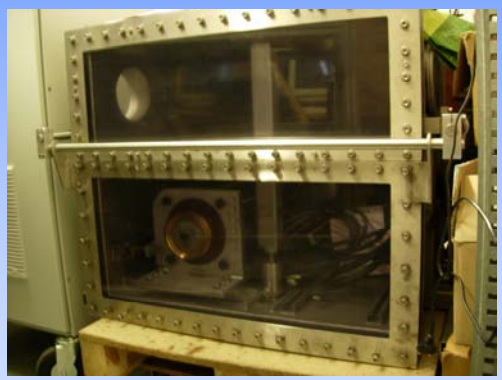
Measurements of component leak flow rates

Cell for hoses and crimps



Cell for compressors

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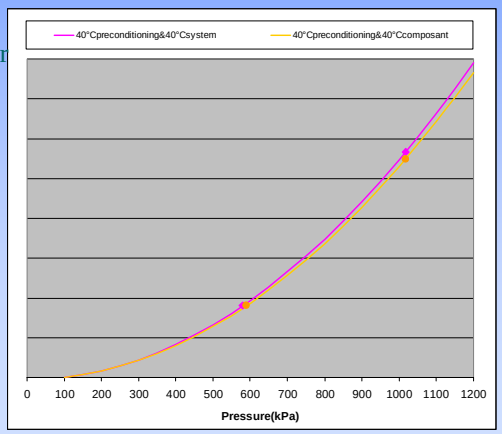
Tests Results and annual prevision

- ✓ Behaviour law expresses the leak flow rate as function of the pressure
- ✓ When knowing the law and the real life emission, a single test temperature can be chosen and a correction factor introduced

g/yr



kPa

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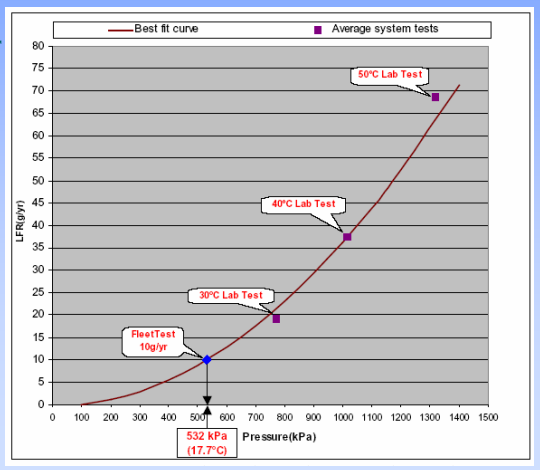
The correlation factor

The average fleet LFR is correlated to the average LFR of systems measured at the laboratory. The chosen laboratory test temperature is of 40°C.

g/yr



kPa

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ACTUAL REFRIGERANT CHARGE

Consequences on energy performances and servicing

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Energy consumption and refrigerant losses

- ✓ ADEME has sponsored a study in order to establish what could be the energy penalty associated to the refrigerant loss along the vehicle lifetime (report for ADEME agreement 05 66 C 0050, July 2006).
- ✓ 10 MAC systems of European cars (vintage 2005) have been selected and tested under realistic conditions.

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Energy consumption and refrigerant losses

- ✓In order to measure realistic data, the test bench has been adapted to the MAC system and not the MAC system to the test bench. This means that the systems have been tested with their original hoses in order to establish the energy consumption including the pressure losses of the real circuit.

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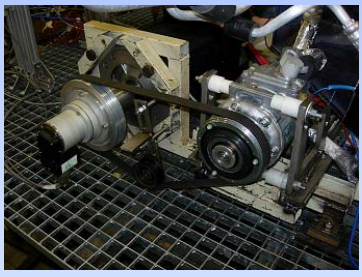
Energy consumption and refrigerant losses

- ✓The input power necessary to run the compressor is measured by a speed meter/torquemeter installed at the end of the electrical motor shaft.
- ✓The cooling capacity is measured on the air side. In order to obtain precise measurements, the recirculation mode has been chosen.



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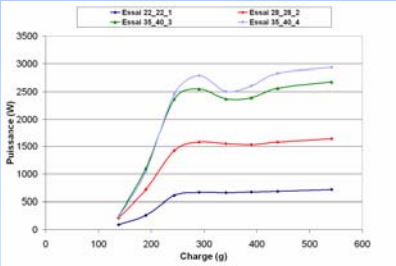
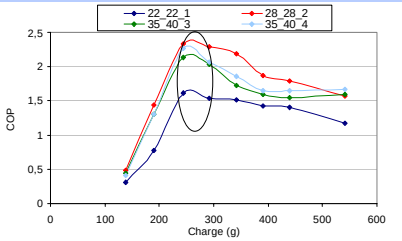
Energy consumption and refrigerant losses

- ✓ For all vehicles, the trend is identical to the one shown on the figure: when lowering the refrigerant charge, the cooling capacity remains nearly constant and the input power is decreasing significantly, meaning that the COP is improved until the optimum refrigerant charge is reached. Then the performance decrease is significant.





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Energy consumption and refrigerant losses

Vehicle	Comp.	Expansion valve	Receiver	Charge (g)	Refrigerant loss before cooling capacity decrease (%)
1	EC	TXV	Integrated HP receiver	550	45
2	IC	TXV	Integrated HP receiver	578	44
3	EC	OT	Suction line accumulator	630	45
4	IC	OT	Suction line accumulator	550	56
5	IC	TXV	HP independent receiver	648	50
6	EC	TXV	Integrated HP receiver	484	52
7	ON/OFF	TXV	Integrated HP receiver	534	53
8	IC	TXV	Integrated HP receiver	543	65
9	IC	OT	Suction line accumulator	573	21
10	EC	TXV	HP independent receiver	900	55

EC: external control
IC: internal control

OT: orifice tube
TXV: thermal expansion valve

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Conclusions

- ✓ The current technologies of micro channels in condensers and plate-and-fin evaporators leads to a small optimum refrigerant charge in the range of 250 g to 300 g, depending on the overall design of the MAC system.
- ✓ The real refrigerant charges vary between 550 and 900 g.
- ✓ This over charge
  - is made in order to compensate the possible emissions of the MAC system (in fact in the warranty period);
  - hampers the system performances.
- ✓ The current refrigerant over charge is more than sufficient to cover the entire lifetime of the MAC system, providing that the leak flow rate is constant along the vehicle lifetime.

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Quality control for no-servicing MAC systems

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Conclusions from the ACEA / ARMINES study and JAMA field tests

- ✓ The average emission rate of recent vehicles is in the range of 10 g/yr. There is a factor 5 between the most and the less emissive systems.
- ✓ The choice of cars for the ACEA / ARMINES study has been random for all the tested vehicles. Some of them have been used for more than one year.
- ✓ Only two of those cars have shown emissions significantly higher than the average value: 45.8 g/yr and 32.3 g/yr.
- ✓ The unknowns are a proportion of ill-assembled MAC systems or poor quality components. Those two issues have to be addressed even if they are based on proprietary information.

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Consequences for MAC system servicing

- ✓ Knowing that the average leak flow rate of new vehicles is low , unnecessary servicing has to be forbidden.
- ✓ No opening of the refrigerant circuit until a clear evidence of refrigerant lack.
- ✓ The refrigerant dehumidifyer/filters have to be designed in order not to be changed during the entire MAC system lifetime.
- ✓ When a MAC system has shown a significant leak coming from one component, this component has to be studied in order to diagnose the failure origin.

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Necessary complementary studies

- ✓ Another critical point is the aging process and how the leak tightness of the MAC system is deteriorating along the year.
- ✓ Complementary studies can be made on significant samples of aged vehicles in order to establish the typical leak flow rate of fleets of aged vehicles.
- ✓ When failures of aged components are diagnosed, it is possible to mimic aging process at the laboratory scale in order to establish probability functions based on physical diagnosis.

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Conclusions

- ✓ Precise measurements of leak flow rate of MAC systems in field tests have deeply changed the usual knowledge of the system refrigerant emissions.
- ✓ A complete picture is still necessary to reconciliate overall data on refrigerant needs for servicing and the actual level of leak tightness of systems.
- ✓ Improvements of leak tightness are still possible and a decrease in leak by a factor 3 can be reached leading to possible no refrigerant servicing systems.

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