Refrigerant Leak flow Rates from MAC systems and components - A European Study ACEA/Armines

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Comments on SAE J2727

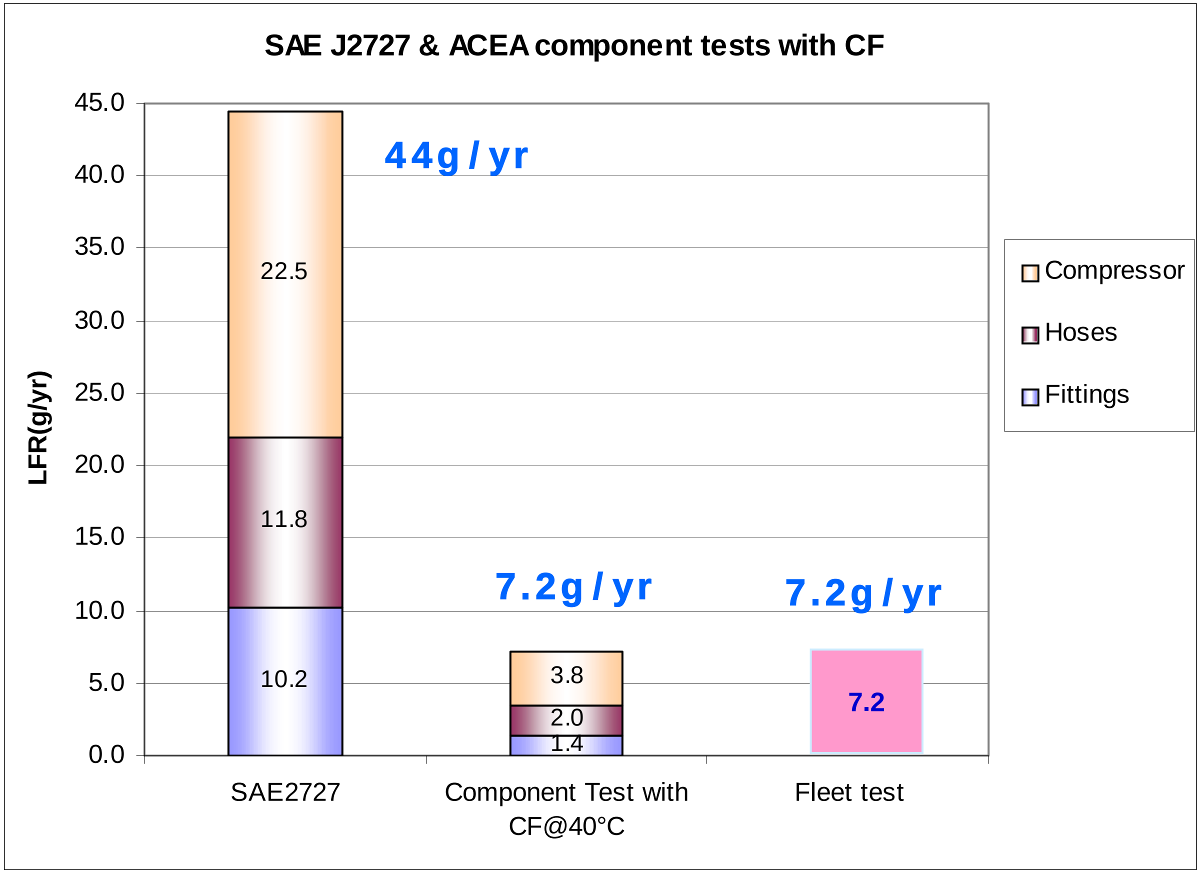
- The standard J2727 provides a rating of technology instead of measured leak flow rates of MAC systems.
- Leak flow rates depending only on technologies need to be demonstrated.

Rigid Pipe Connections and Flexiable Hose Connections	Single O-ring	Single Captured O-ring	Multiple O-ring
Total Emissions	125	75	50
	1.25 g/yr	0.75 g/yr	0.50 g/yr

	Single Lip+ Body O-rings	Single Lip+Body Gaskets	Multiple Lip and Body O-rings	Multiple Lip + Gaskets
Total Emissions	2500	2000	1200	700
Compressor	1			
	25 g/yr	20 g/yr	12 g/yr	7 g/yr

SAE J2727 vs. ACEA tests

- MAC System X



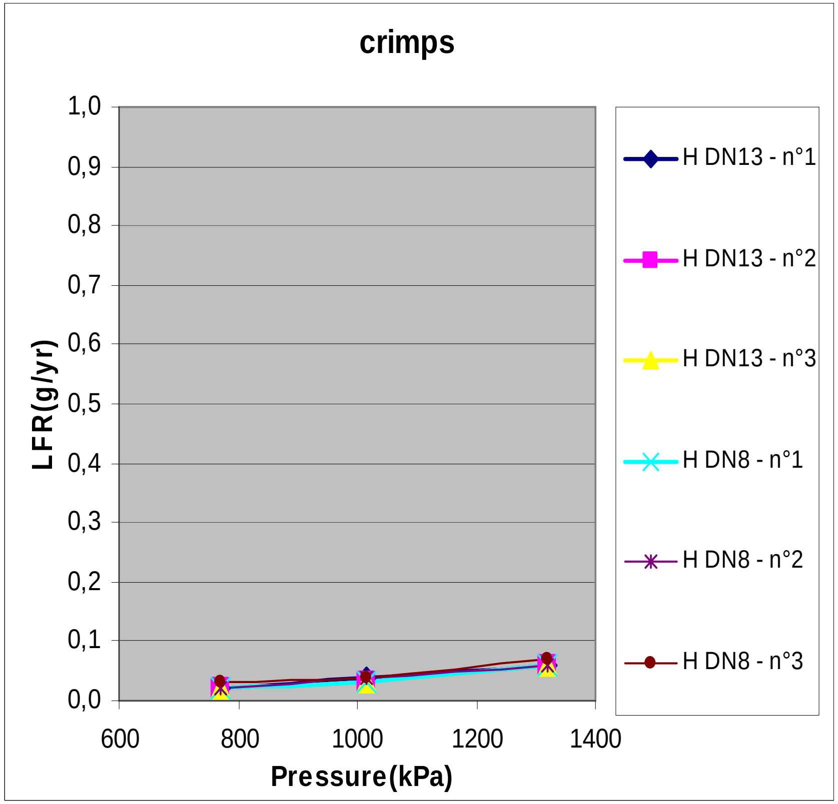
•The MAC system is classified 4.4 meaning a LFR of 44 g/yr, which is significatively higher than the results of the ACEA fleet test (7.2 g/yr).

•Results based on measurements of LFR of components and using the Correlation Factor (see EU test approval method) show the same leakage level compared to real life test.

LFRs of MAC components - Crimps

- Results on six new crimps show that Leak Flow Rates of crimps are low enough to be neglected.

CRIMPS	Description	LFR(g/yr)			Estimated LFR(g/yr)
Temperature(°C)		50°C	40°C	30°C	
Saturation Pressure(kPa)		1318	1017	770	
H	DN13 - n°1	0.06	0.04	0.02	0.01
H	DN13 - n°2	0.06	0.03	0.02	0.01
H	DN13 - n°3	0.06	0.03	0.02	0.01
H	DN8 - n°1	0.06	0.03	0.02	0.01
H	DN8 - n°2	0.06	0.04	0.02	0.01
H	DN8 - n°3	0.07	0.04	0.03	0.01



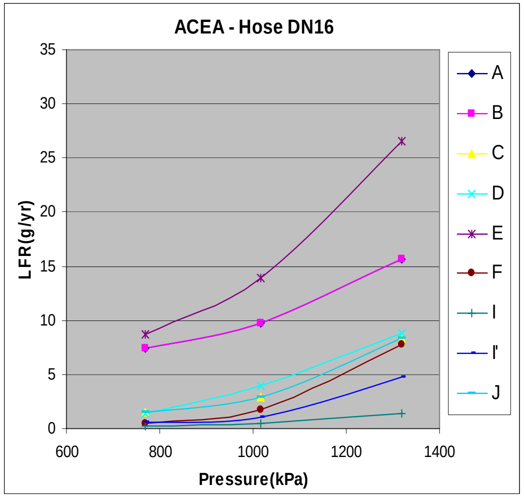
Estimated LFR is calculated based on the EU test approval method:

$$\text{Annual LFR} = \text{LFR}_{40°C} \times 0.277 (\text{Correction Factor})$$

LFRs of MAC components - Hoses

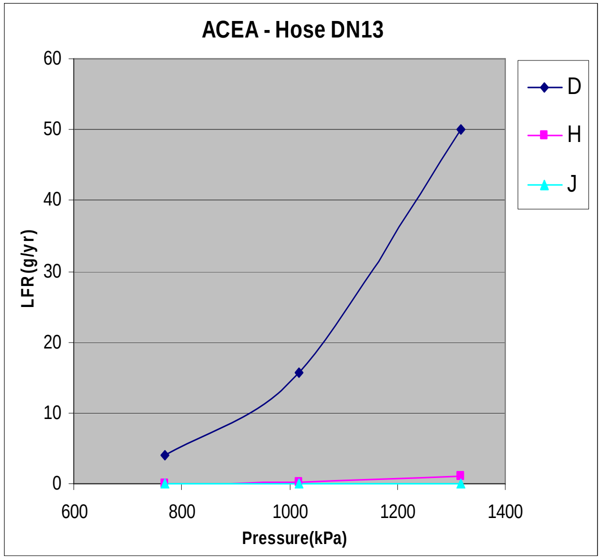
- Based on the results of measurements, current classification of LFRs of hoses are not perfectly adapted.
- Predictive model for hose emissions based on measurement of diffusion coefficient through the different materials and for different thicknesses are possible and need additional work.

DN16



system	DN [mm]	TECHNOLOGY	LFR(g/yr)		
Temperature(°C)			50°C	40°C	30°C
Saturation Pressure(kPa)			1318	1017	770
A	16	<IIR-EPDM>	15,6	9,7	7,4
B	16	<IIR-EPDM>	15,6	9,7	7,4
C	16	>CIIR-PET-CR<	8,4	2,9	1,5
D	16	PA/IIR/PET/EPDM	8,8	3,9	1,4
E	16	>EPDM-SF-CIIR<	26,5	13,9	8,7
F	16	>CIIR-PVA-PA-CR<	7,8	1,7	0,5
I	16	PA/IIR/PET/EPDM	1,34	0,51	0,21
I	16'	PA/IIR-PES-EPDM	4,79	1,03	0,56
J	16	>CIIR-PET-CR<	8,4	2,9	1,5

DN13

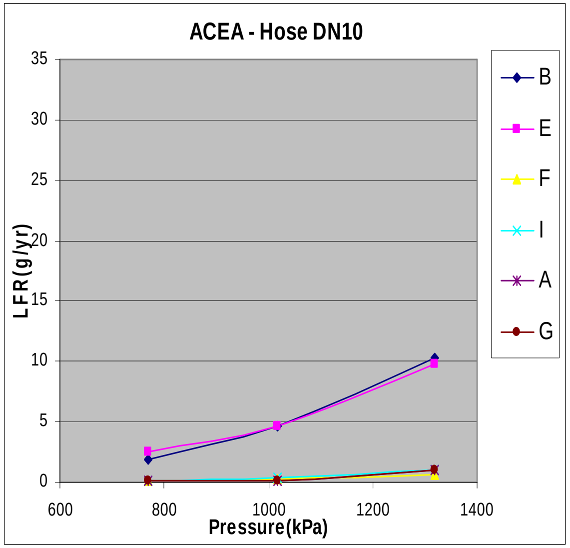


system	DN [mm]	TECHNOLOGY	LFR(g/yr)		
Temperature(°C)			50°C	40°C	30°C
Saturation Pressure(kPa)			1318	1017	770
D	13	>PA6-HNBR/AR/HNBR<	50,0	15,6	4,1
H	13	PA-IIR-PES-EPDM	1,02	0,30	0,07
J	13	PA6<>EPDM<>PVAL><AEM<	0,09	0,03	0,01

LFRs of MAC components - Hoses

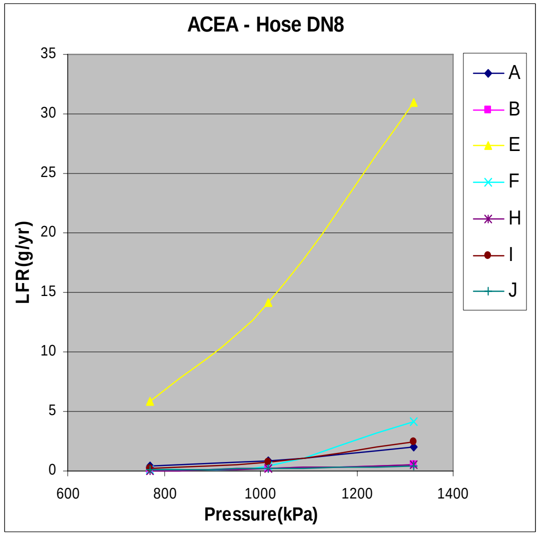
- Based on the results of measurements, current classification of LFRs of hoses are not perfectly adapted.
- Predictive model for hose emissions based on measurement of diffusion coefficient through the different materials and for different thicknesses are possible and need additional work.

DN10



system	DN [mm]	TECHNOLOGY	LFR(g/yr)		
Temperature(°C)			50°C	40°C	30°C
Saturation Pressure(kPa)			1318	1017	770
B	10	<IIR-EPDM>	10,23	4,70	1,87
E	10	>EPDM-SF-CIIR<	9,8	4,6	2,5
F	10	>CIIR-PVA-PA-CR<	0,6	0,2	0,1
I	10	PA/IIR/PET/EPDM	1,01	0,4	0,09
A	10,5	>PA< >EPDM<	0,97	0,18	0,09
G	10,5	>PA< >EPDM<	0,97	0,18	0,09

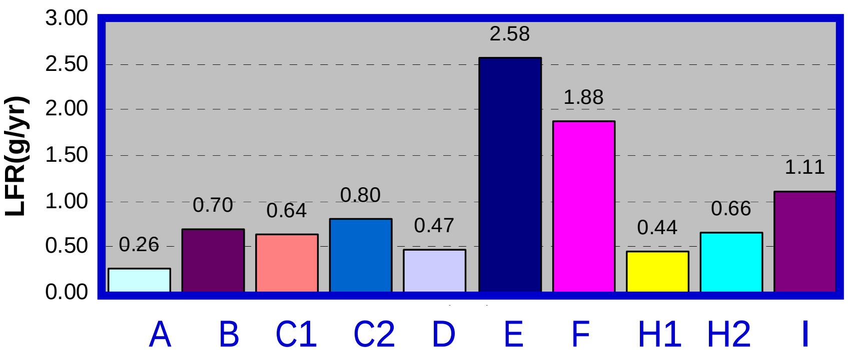
DN8

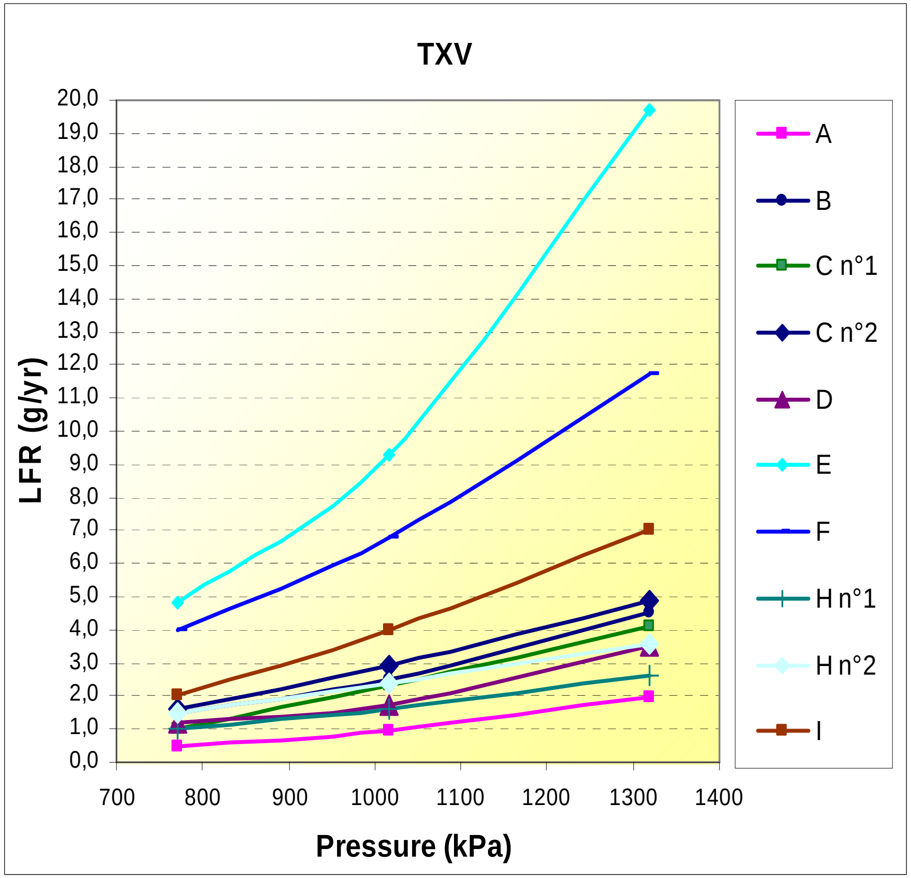


system	DN [mm]	TECHNOLOGY	LFR(g/yr)		
Temperature(°C)			50°C	40°C	30°C
Saturation Pressure(kPa)			1318	1017	770
A	8	>PA< >EPDM<	1,98	0,85	0,4
B	8	<IIR-EPDM>	0,49	0,22	0,11
E	8	>EPDM-SF-CIIR<	31	14,1	5,8
F	8	>CIIR-PVA-PA-CR	4,2	0,4	0,1
H	8	PA/IIR/PET/EPDM	0,54	0,16	0,02
I	8	PA-IIR-PES-EPDM	2,45	0,7	0,23
J	8	>PA-IIR/PET/CIIR<	0,45	0,19	0,08

LFRs of MAC components - TXV

TXV list	LFR(g/yr)			Estimated LFR (g/yr)
	50°C 1318 kPa	40°C 1017 kPa	30°C 770 kPa	
A	1.95	0.95	0.5	0.26
B	4.52	2.52	1.5	0.70
C n°1	4.1	2.3	1	0.64
C n°2	4.9	2.9	1.6	0.80
D	3.5	1.7	1.2	0.47
E	19.7	9.3	4.8	2.58
F	11.7	6.8	4	1.88
H n°1	2.6	1.6	1	0.44
H n°2	3.6	2.4	1.5	0.66
I	7	4	2	1.11

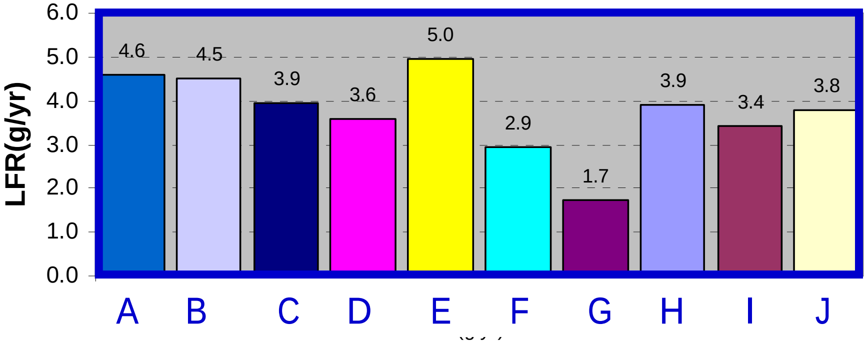


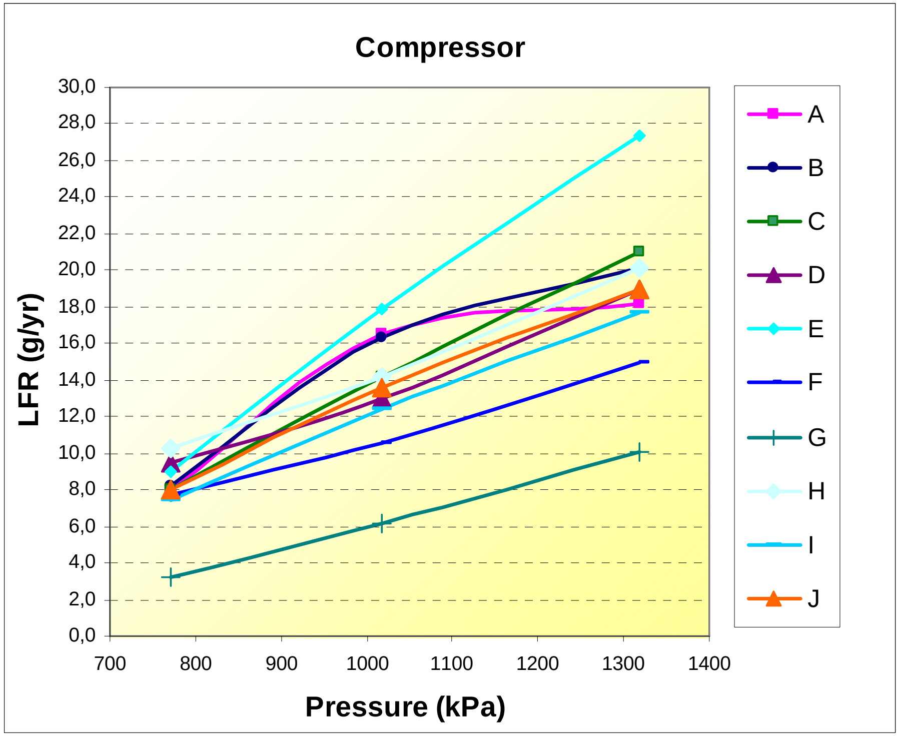


LFRs of MAC components - Compressor

- Among 10 tested compressors, annual leak flow rates vary between 1.7 and 5.0 g/yr. This significant difference shows the need for more detailed study.

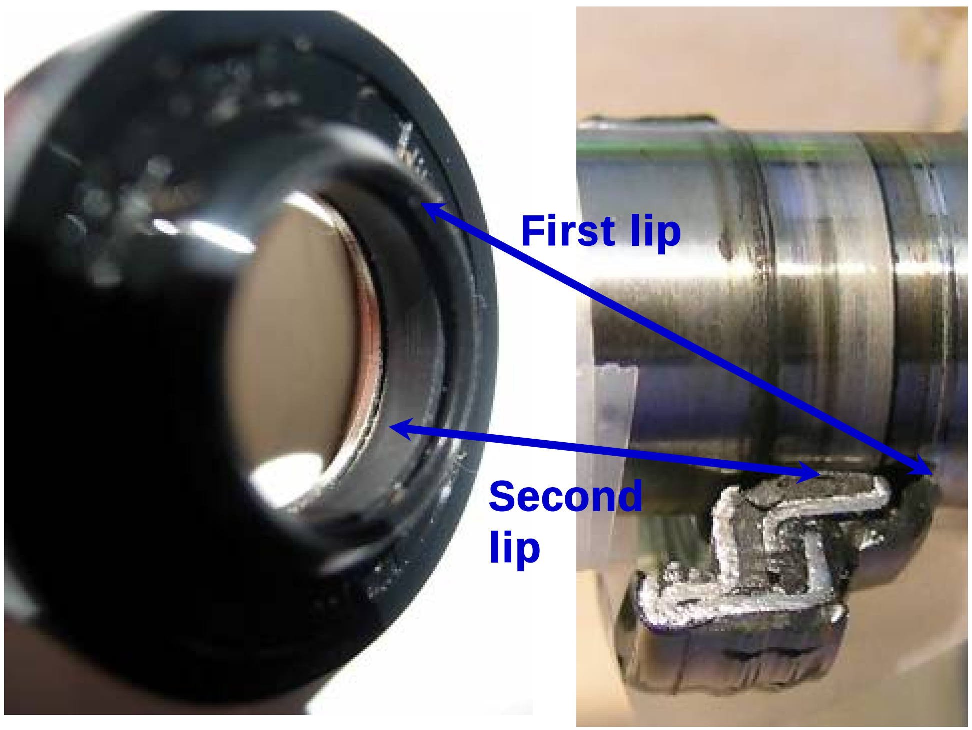
compressor list	LFR(g/yr)			Estimated LFR (g/yr)
	50°C 1318 kPa	40°C 1017 kPa	30°C 770 kPa	
A	18.2	16.5	8.0	4.6
B	20.1	16.3	8.2	4.5
C	21.0	14.2	8.0	3.9
D	19.0	13.0	9.5	3.6
E	27.4	17.9	9.0	5.0
F	15.0	10.6	7.7	2.9
G	10.1	6.2	3.2	1.7
H	20.1	14.2	10.3	3.9
I	17.7	12.4	7.4	3.4
J	19.0	13.6	8.0	3.8





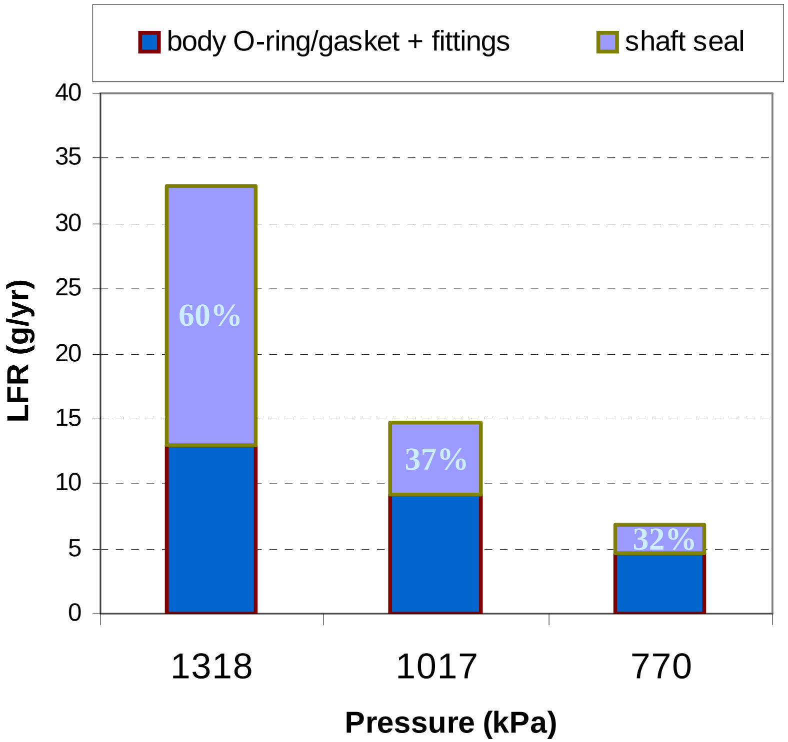
LFRs of MAC components - Compressor

- Shaft seal of compressor is always multi-lip.



- Contribution of shaft seal is variable with respect to test condition

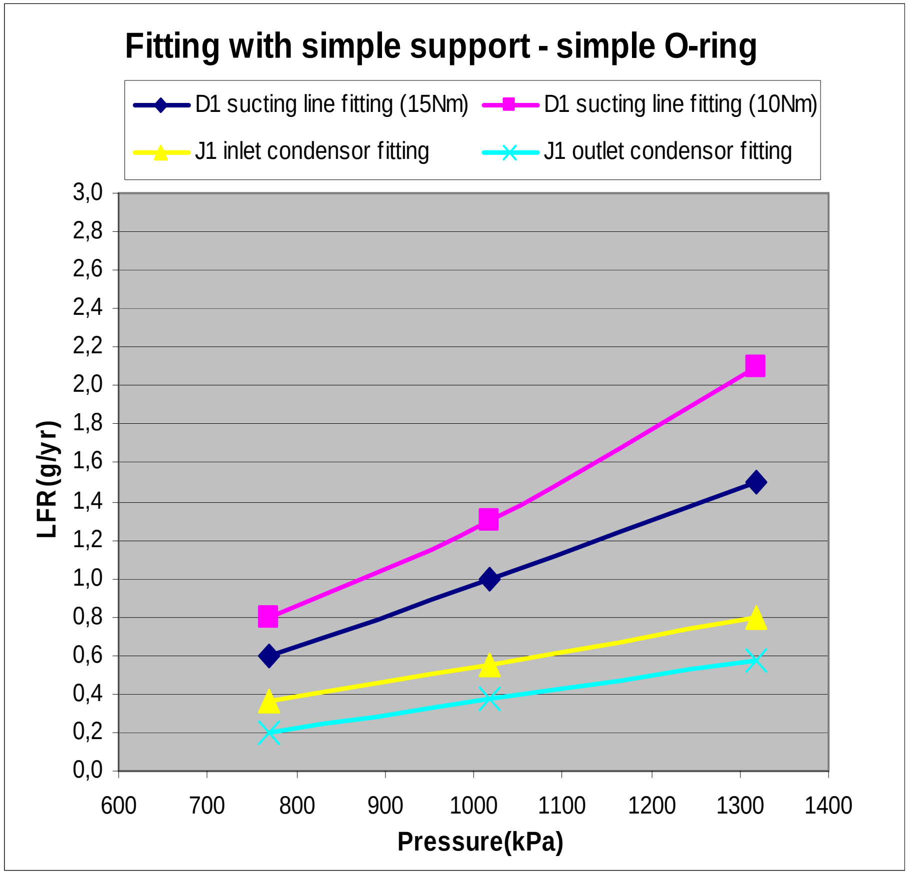
compressor test	LFR(g/yr)		
	50°C 1318 kPa	40°C 1017 kPa	30°C 770 kPa
shaft seal + body O-ring/gasket + fittings(1)	32.9	14.7	6.8
body O-ring/gasket + fittings(2)	13	9.2	4.6
shaft seal(1-2)	19.9	5.5	2.2
contribution of Shaft Seal	60%	37%	32%



LFRs of MAC components - Fittings

- Simple support single O-ring

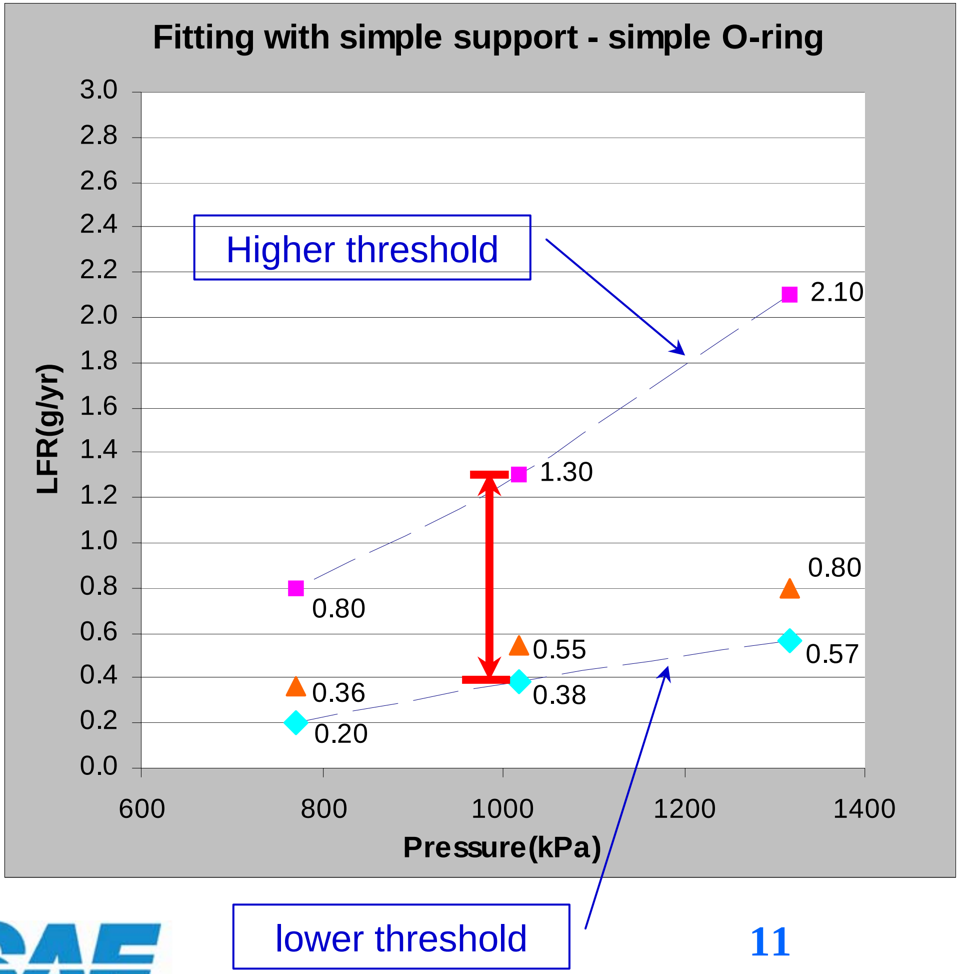
System	Description	LFR(g/yr)		
Temperature(°C)		50°C	40°C	30°C
Saturation Pressure(kPa)		1318	1017	770
D1	sucting line fitting (15Nm)	1,50	1,00	0,60
D1	sucting line fitting (10Nm)	2,10	1,30	0,80
J1	inlet condensor fitting	0,80	0,55	0,36
J1	outlet condensor fitting	0,57	0,38	0,20



LFRs of MAC components - Fittings

- Simple support single O-ring

Establishment of thresholds for fittings



Based on the results of 3 fittings belonging to the same technology, LFRs at 40°C of fittings with simple O-ring vary between 0.38 and 1.30 g/yr.

By applying the Correlation Factor of 0.277, the real life leakage is in the range of **0.11~0.36** g/yr.

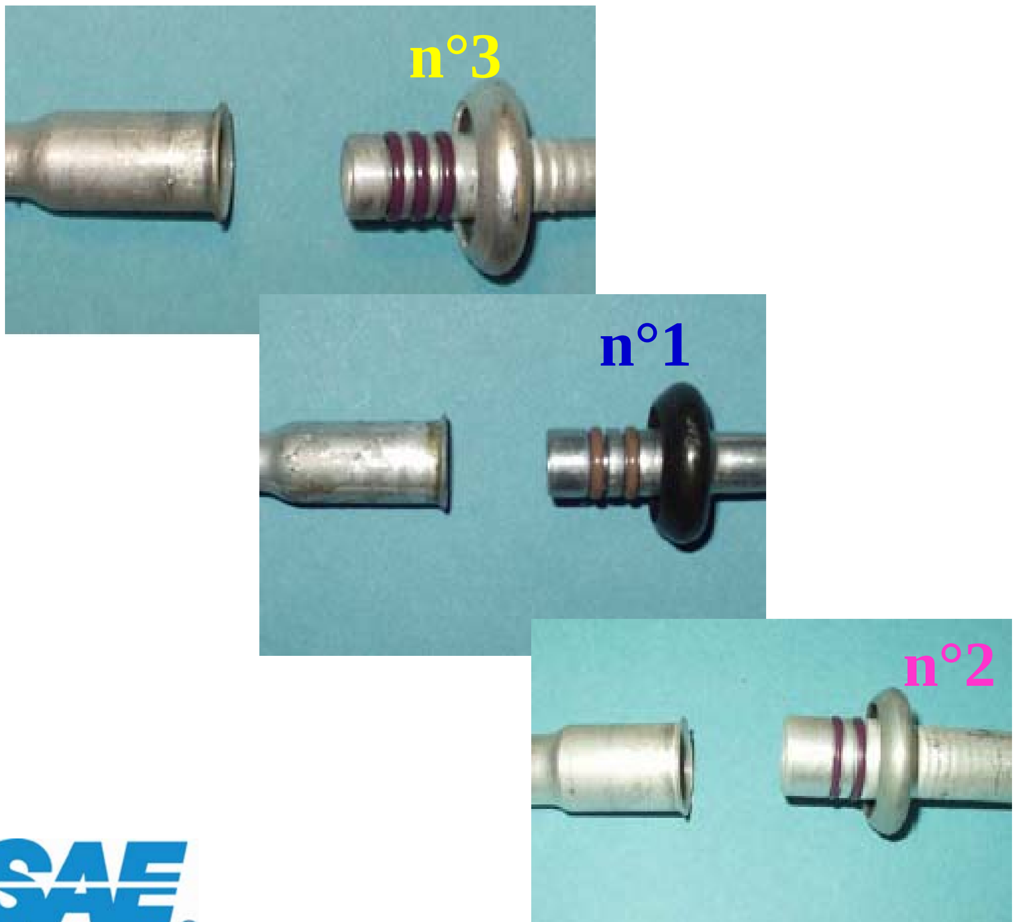
$$0.11 g / yr < LFR < 0.36 g / yr$$

LFRs of MAC components - Fittings

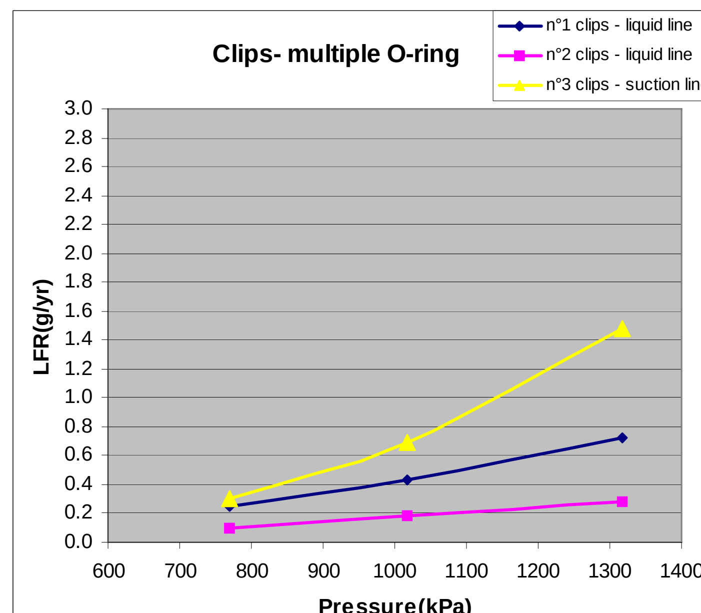
- Cilps with double and triple O-ring

The same number of O-rings does not generally give the same LFR(n°1,n°2), moreover it is not always true that ⟹

$$LFR \propto \frac{1}{number_{O-ring}} \quad (n°3)$$



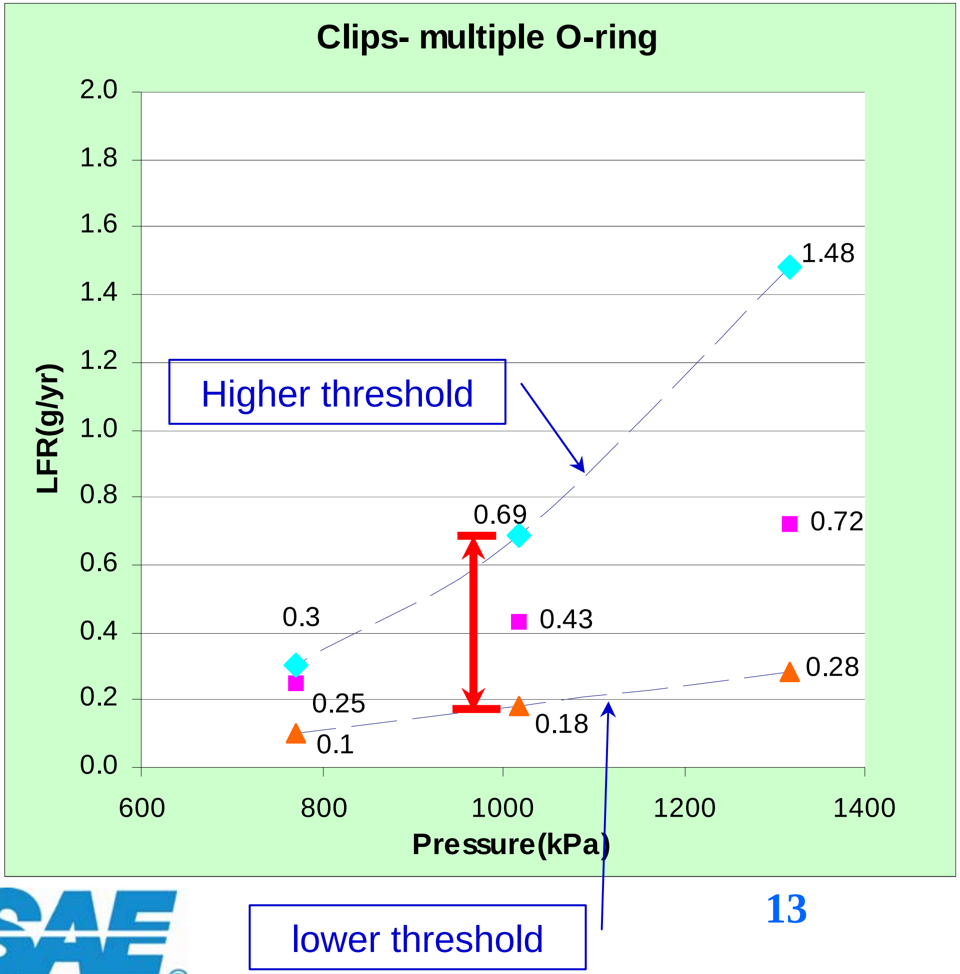
System	Description	LFR(g/yr)		
Temperature(°C)		50°C	40°C	30°C
Saturation Pressure(kPa)		1318	1017	770
n°1	clips - liquid line	0,72	0,43	0,25
n°2	clips - liquid line	0,28	0,18	0,1
n°3	clips - suction line	1,48	0,69	0,3



LFRs of MAC components - Fittings

- Cilps with double and triple O-ring

Establishment of thresholds for fittings



LFRs at 40°C of fittings with multiple O-rings vary from 0.18 to 0.69 g/yr.

By applying the CF of 0.277, the real life leakage is in the range of **0.05~0.19** g/yr.

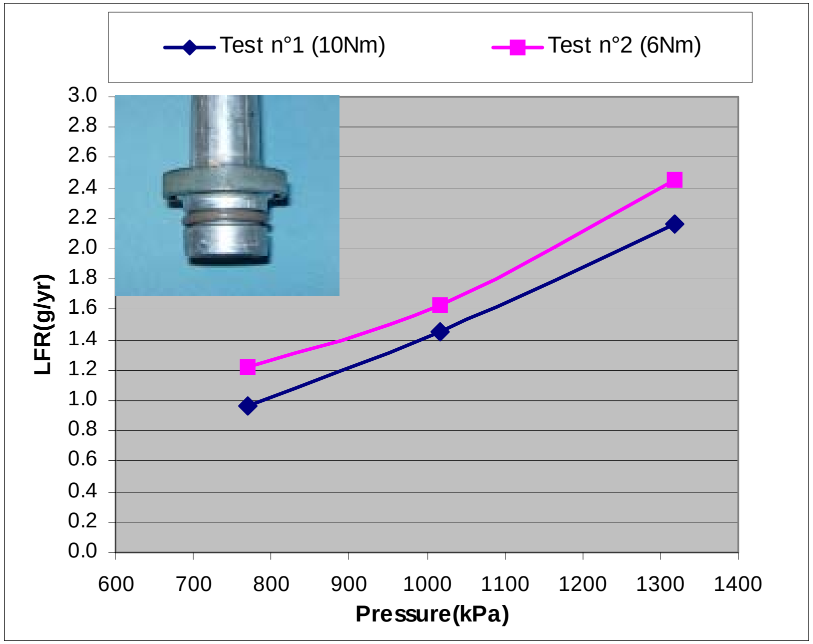
$$0.05\,g/yr < LFR < 0.19\,g/yr$$

LFRs of MAC components

■ Impact of tightening torques

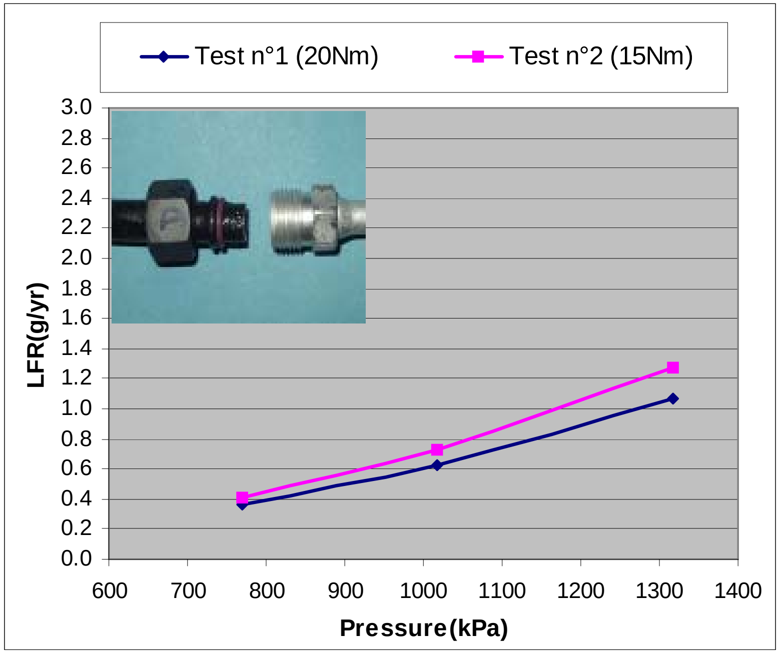
Single O-ring with simple support

Fitting	Description	LFR(g/yr)		
Temperature(°C)		50°C	40°C	30°C
Saturation Pressure(kPa)		1318	1017	770
Test n°1 (10Nm)		2.16	1.45	0.97
Test n°2 (6Nm)		2.45	1.63	1.22



Single O-ring with screwed ends

System	Description	LFR(g/yr)		
Temperature(°C)		50°C	40°C	30°C
Saturation Pressure(kPa)		1318	1017	770
D1	fitting (20Nm)	1,07	0,62	0,36
D1	fitting (15Nm)	1,27	0,73	0,41



LFRs of MAC components

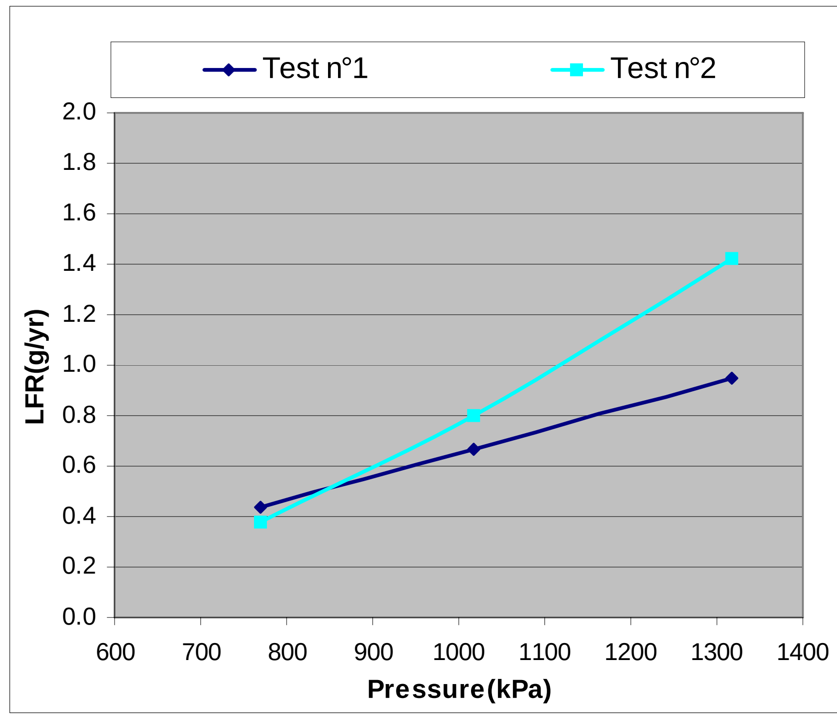
- Impact of clearance

Clips

Test n°1

Test n°2

Fittings	Description	LFR(g/yr)		
Temperature(°C)		50°C	40°C	30°C
Saturation Pressure(kPa)		1318	1017	770
Test n°1		0.95	0.67	0.44
Test n°2		1.42	0.80	0.38



Conclusions

- Based on the results of component tests for ACEA, LFRs of heat exchangers and crimps are quite low and can be neglected.
- Systematic measurements are required to verify the repeatability (4 to 10 samples) and reproducibility of the LFRs of fittings for the same technologies. All technologies have to be measured.
- Due to complex design and many sources of leakage (6 possible locations) of TXV, it is proposed to be tested per se.
- Compressor emissions are dominant and measurements have to be developed to understand the variation of more than a factor 3 between the worse and the best technologies.
- Predictive model for hose emissions based on measurement of diffusion coefficient through the different materials and for different thickness.
- Extensive work is required in order to establish lower and higher thresholds of LFRs for each and every technology.