Evaluation of the Potential Impact of Emissions of HFC-134a From Non Professional Servicing of Motor Vehicle Air Conditioning Systems

CARB Agreement No. 06-341

Prepared for

State of California Air Resources Board
Research Division
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Final Report

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December 2008

DISCLAIMER

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Abstract

This project included laboratory testing and field studies to evaluate the methods and procedures used by both professionals and non-professionals while servicing mobile air-conditioning (MAC) systems. A majority of professional technicians used recovery and recharge machines with some using small cans. All non-professional do-it-yourself (DIY) individuals used small cans. Field testing was also conducted to determine refrigerant emissions from non-professional servicing. While the data indicated that the majority of the refrigerant was charged into the MAC systems, thirty-three percent was emitted to the atmosphere. Laboratory testing was performed to measure the leak rate from small cans and charging hoses and to compare different leak detection techniques used by professional technicians. In addition, testing was conducted to measure the initial leak flow rate of new MAC systems installed in the 5 most popular vehicles in California.

Executive summary

Background

This research project will assist ARB in the mitigation of Climate Change as required in the California Global Warming Solutions Act. Specifically, the results of this study will assist in the development of a regulatory measure reducing the emissions of high global warming potential (GWP) refrigerants used by non-professional individuals in re-charging their motor vehicles' air conditioning (MVAC) systems. ARB is interested in gaining an understanding of the nature of non-professional MVAC servicing and the resulting emissions of high-GWP refrigerant. In addition, ARB wants to evaluate professional servicing of MVAC systems in order to understand its advantages in comparison to non-professional servicing. The data and information from this project could be beneficial for the development other potential measures concerning high-GWP refrigerants used in MVAC systems, emission reductions from leaking MVACs, and professional servicing.

Method

This research project consisted of two parts. In one part, ARMINES' Center for Energy and Processes (CEP) staff conducted field testing and field evaluations of non-professional DIY MVAC servicing and a field survey and evaluation of professional MVAC servicing. The rest of the project included the laboratory testing of different MAC systems, DIY containers and charging hoses, and different leak detection techniques used by professional technicians.

The field testing included the measurement of the refrigerant emissions from non-professionals performing MAC servicing using "small cans." Refrigerant emissions were determined by taking a mass balance approach where an individual performed a "small can" re-charge on a MVAC system containing a known quantity of refrigerant. This is followed by weighing the container to determine the remaining refrigerant and refrigerant recovery from the MVAC system in order to determine how much refrigerant was charged into the system by the non-professional. In addition, the individuals performing the DIY practice were profiled and the procedures used during the MVAC re-charging were characterized and evaluated. This latter qualitative approach was also used with professional technicians who were asked to diagnose and perform corrective actions on an undercharged MAC system provided in a CEP vehicle. The professionals' diagnoses and servicing recommendations were compiled and evaluated.

The laboratory testing was conducted at the CEP facility and included the measurement of the performance of a single MVAC system which was mounted on a test bench. During the test, system parameters, including evaporator air temperature, were measured to observe how the cooling performance decreased as the refrigerant charge was reduced.

CEP staff also measured the leak rates of automotive refrigerant containers and the hose assemblies before and after container valve actuation. The containers and container/hose assemblies were placed inside an accumulation volume and an infrared spectrophotometer was used to measure the rise in refrigerant concentration inside the volume over time. Testing was also conducted to compare the sensitivity of different leak search methods using a leak detector, ultraviolet dye with a lamp, and soap/water solution on a pressurized MVAC system joints. In addition, CEP staff measured the annual leak flow rates (LFRs) of the MAC systems on the five most sold cars in California in a laboratory. The laboratory testing was performed in mini-sheds (small chambers) at the CEP facility. All of these leak tests were performed using a methodology specified in the European Regulation 706/2007.

Results

Non-professional Servicing

In general, it was observed that DIY individuals recharge their MVAC systems without knowing the amount of refrigerant remaining in the MVAC system, the manufacturers' specified refrigerant charge, and without making a diagnosis of any problems including a search for leaks. Moreover, instructions on the container's label give incorrect information about re-charging the air conditioning system. Results from the field testing of the non-professionals indicate that two-thirds of the refrigerant in the small can is charged into the MAC system with the remainder released to the atmosphere. Refrigerant emissions from the DIY procedure is split with two thirds remaining in the container (can heel) which is eventually breached releasing the contents to the atmosphere. One third is released to the atmosphere during recharging. Based on a field survey, the typical cost of a can plus the recharging kit varies from $15 to $ 40.

Professional Servicing

One of the benefits of professionals servicing is the diagnosis of problems with MVAC operation along with the servicing or repair. Most professional technicians measure the air temperature coming from the vents in the cabin, check the compressor clutch actuation, and measure the high and low pressures of the system. The vast majority of the technicians recommend the use of ultraviolet-sensitive dye with a UV lamp to detect leaks. Some use electronic detectors. All of these methods have detection limits below which these methods will not work. The majority of professional repair and servicing facilities use automated recovery and recharge machines which minimize refrigerant emissions during servicing. The cost of professional servicing ranges from $80 to $200 for diagnosis, recovery and recharge with a machine, and, depending on the shop, includes a leak search. This estimate does not include the more costly repairs such as replacing a compressor.

Laboratory Testing

Testing in the lab allowed CEP staff to collect data for MVAC systems and components under situations that we would not have been possible in the field. The results of the collection of MVAC performance data versus decreasing refrigerant charge indicated that there is no significant deterioration in the cooling performance until the refrigerant was reduced to approximately half of manufacturer's specified charge.

Testing was also conducted to compare three leak detection methods which included the use of an electronic leak detector, the detection of soap bubbles on a MVAC system pressurized with CO_2 or air, and the injection of UV-sensitive dye into a system with the use of a UV lamp to detect leaks. Data from the testing indicates that the usage of UV dye is capable of detecting a leak of 6 g/yr with an 11 hour waiting period. This is as sensitive as an electronic leak detector and more sensitive than the soap bubble detection method.

For the leak rate measurement of small containers, there is no significant emission difference between the screw-and-perforate (S&P) and valve-equipped cans prior to usage. However, when considering a used container the leak rates for the "push-button" type charging kits on the S&P containers were very significant when compared to the valve-equipped cans or the S&P containers with the shut-off valve installed.

The average annual LFR of the five most sold MAC systems in California is
10±4 grams per year which indicates that U.S. MVAC systems are comparable to the European and Japanese systems in terms of leakage.

Conclusions

There are significant differences between professional and non-professional servicing operations. The use of small cans by non-professionals results in emissions of about 1/3 of the refrigerant contained in small cans. It is possible that "small can" usage by professionals may result in lower emissions. The most significant advantage of professional servicing, in terms of emissions, is the use of an automated R&R machine which results in re-charging emissions that may be lower than 5 g per operation. This compares favorably to refrigerant emissions of more than 110 g per servicing when non-professionals use small cans.

The initial leak tightness of U.S.-made MAC systems is in the neighborhood of 10 grams per year. If this leak tightness were to be maintained over a lifetime, no recharge should be necessary for 15 years. However, HFC-134a sales indicate that the leak flow rates of MAC systems increase with time with many MVACs requiring service after 6 to 8 years of operation.

Introduction

The main objective of this research project was to develop experimental data in order to better estimate emissions of HFC-134a due to non-professional servicing of MAC systems. The overall study design was divided into six tasks and are presented as follows:

- Measurements of initial leak flow rate (LFR) of the five most used MAC systems in California
- Analysis of current recharge by non-professionals in California
- Analysis of current leak search and recharge by professional servicing in California
- Laboratory tests simulating non-professional operating modes in California
- Evaluation of the sales of HFC-134a disposable cans in California
- Recovery of samples of disposable cans after usage by non-professionals in California

1. Measurements of initial leak flow rate (LFR) of the five most used MAC systems in California

1.1 Test method

The test bench dedicated to the leak flow rate measurement of the whole AC system has been developed by CEP [ACE05]. The leak measurements are performed in accordance with the European directive 2006/40/EG [EUD06]. The test procedure detailed by the European regulation 706/2007 [EUR07] is described below.

The MAC system (see Photo 1.1) is first mounted, evacuated and charged with the nominal manufacturer refrigerant charge (±1 gram) and then installed inside the mini-shed.

According to the specifications given by EUR07, the pre-conditioning is performed at 50℃ for 10 days. Thereafter, the mini-shed is rinsed and tests are carried out at 40℃. In order to establish a regression correlation on the five U.S. MAC systems, three temperatures are successively controlled in order to measure the three corresponding leak flow rates (LFR).

Photo 1.1: Installation of MAC system in mini-shed.

An infrared photo-acoustic spectroscope, having a detection limit of 15 ppb, measures the refrigerant accumulated inside the mini-shed. The mass flow rate is the product of the molar mass and the derivative of the number of moles of HFC-134a with respect to time in the test chamber volume (the test chamber). The perfect gas law is used to take into account the small variations of pressure and temperature inside the test chamber. According to Equation (1.2), the following parameters need to be determined for leak flow rate calculation: the accumulation volume of the test chamber V_{accum}, the temperature T_{amb} and the pressure P_{amb} inside the test chamber, and the evolution of concentration with time.

The method used to determine the leak flow rate (LFR) is based on Equation (1.1).

$$\dot{m}_{HFC-134a} = M_{HFC-134a} \cdot \frac{\partial n_{HFC-134a}}{\partial t} \qquad \text{Equation(1.1)}$$

Where,

$$n_{HFC-134a} = n_{total} \cdot C = \frac{P_{amb} \cdot V_{accum}}{R \cdot T_{amb}} \cdot C \qquad \text{Equation(1.2)}$$

$\dot{m}_{HFC-134a}$	HFC-134a mass flow rate ($g.s^{-1}$)
$M_{HFC-134a}$	HFC-134a molar mass (102 $g.mol^{-1}$)
$n_{HFC-134a}$	Number of mole (mol)
t	Time (s)
C	Refrigerant concentration (ppm)
P_{amb}	Ambient pressure (Pa)
V_{accum}	Accumulation volume (m^3)
R	Gas constant ($8.314x10^3$ kJ $kmol^{-1}$ K^{-1})
T_{amb}	Ambient temperature (K)

1.2 Tests results

All five MAC systems were purchased from each manufacturer and mounted in the CEP test chambers according to manufacturers specifications and instructions.

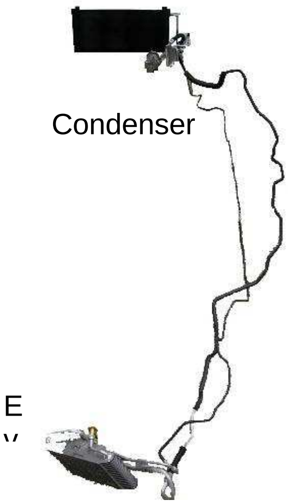
1.2.1 MAC system A

System specifications

Table 1.1 System specifications.

Reference	System A
Type	SUV
Motorization	/
Vintage	2002-2004
MAC system	Dual evaporator
Nominal refrigerant charge	1400 g

System design



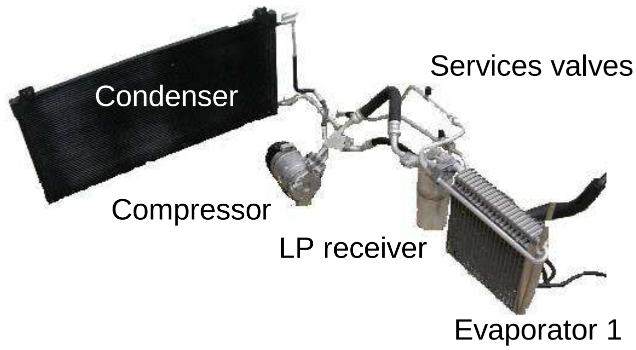


Photo 1.2 Assembled MAC system A.

Table 1.2: List of components.

Components	Numbers of components	Comments
Compressor	1	
Condenser	1	
LP receiver	1	Located on the outlet of the evaporator 1
Evaporator	2	
Expansion valve	2	Evaporator 1: Orifice tube Evaporator 2: TxV
Liquid line	3	
Suction line	2	
HP service valve	1	Located on the discharge line
LP service valve	2	Located on the liquid line 1 & 2
HP sensor	1	Located on the discharge line
LP sensor	1	Located on the LP receiver

Leak flow rate calculation

Table 1.3 summarizes the MAC system A leak flow rates for 3 different temperatures.

Figure 1.1 illustrates the leak flow rate as a function of pressure.

Table 1.3: LFRs of MAC system A.

T(℃)	Saturation Pressure (kPa)	LFR (g/yr)
30	770	13.0 ± 0.8
40	1017	25.3 ± 1.5
50	13118	44.8 ± 2.7

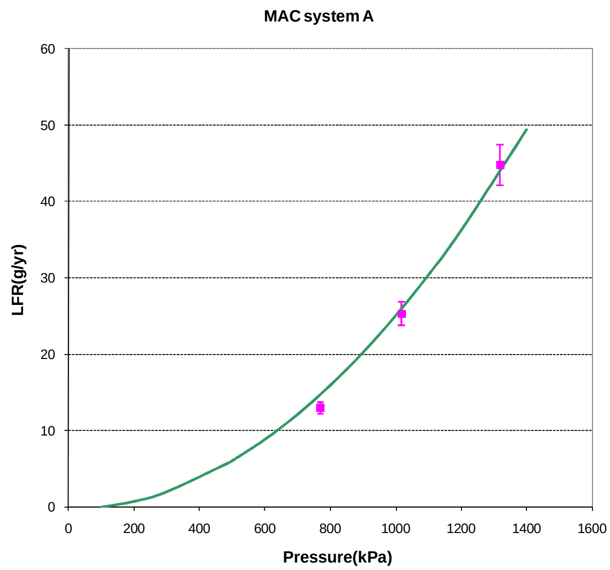


Figure 1.1 LFRs & Regression curve.

Using the method of least squares, a good relationship between the measured values and the regression curve of the binomial expression has been verified and is expressed by Equation 1.3.

$$LFR = k(P_{upstream}^2 - P_{downstream}^2) \quad \text{Equation(1.3)}$$

The objective of this approximation is to find a general approach for MAC system leakage behavior as a function of pressure, which will be used for leak flow rate prediction at a required temperature. Once the equation parameter K is determined, the MAC leak flow rate is then calculated at the corresponding temperature for each zone.

Considering the population for 10 California zones, the LFR is determined as a function of the temperature for the saturation pressure and then related to the population.

Example: taking the Arcata zone (see Table 5), a mean temperature of 10.4℃ corresponds to the saturation pressure of 420 kPa. Using Equation 1.3, a leak flow rate value of 4.2 g/yr ($2.536x10^{-5}$ *(420^2-101^2)) is obtained.

Table 1.4 Determination of the annual LFR of MAC system A taking into account CA population.

	Arcata	Bakersfield	Daggett	Fresno	Long Beach	Los Angeles	Sacramento	San Diego	San Francisco	Santa Maria	Total
Annual mean T(℃)	10.4	18.5	19.8	17.1	17.2	16.7	15.2	17.6	13 .1	12.9	
Saturation Pressure(kPa)	420	546	568	522	523	516	492	530	459	456	
K= 2.536E-05											
LFR(g/yr)	4.2	7.3	7.9	6.7	6.7	6.5	5.9	6.9	5.1	5.0	
Population	790525		4669274	2962948		12901515	3443421	2933929	5966569	2173073	35841254
% Population	2.2%		13.0%	8.3%		36.0%	9.6%	8.2%	16.6%	6.1%	100%
LFR%	0.1		1.0	0.5		2.3	0.6	0.6	0.8	0.3	**6.3**

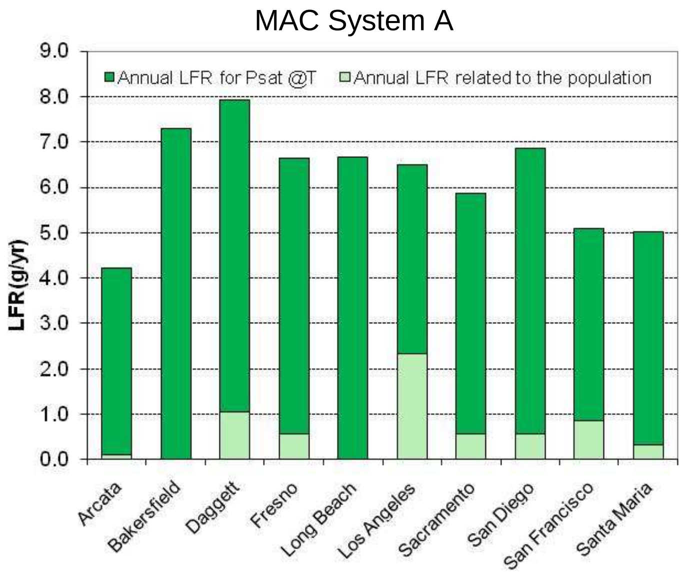


Figure 1.2 LFR variations taking the population into consideration.

Figure 1.2 shows the annual leak flow rate corresponding to the zone temperature as well as the annual leak flow rate related to the population.

1.2.2 MAC system B

System specifications

Table 1.5 System specifications.

Brand	MAC system B
Type	Van
Motorization	3.3 l SMPI
Vintage	2005
MAC system	Dual evaporator
Nominal refrigerant charge	1080 g

System design

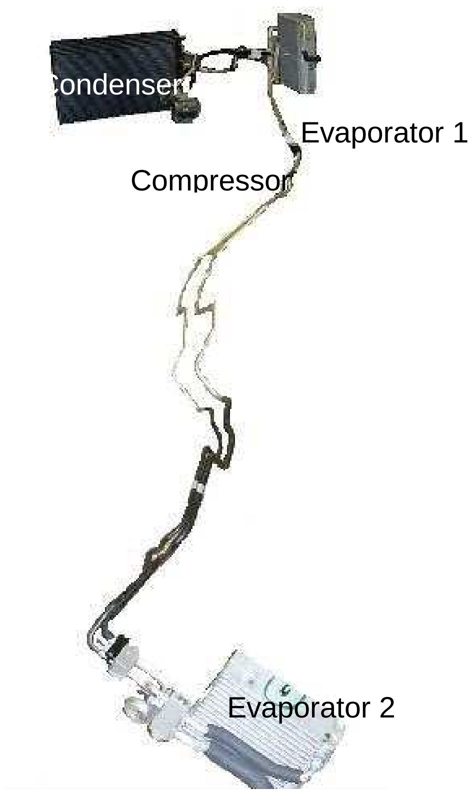


Photo 1.3 Assembled MAC system B.

Table 1.6 List of components.

Components	Numbers of components	Comments
Compressor	1	
Condenser	1	
HP liquid receiver	1	Located on the principal liquid line
Evaporator	2	
Expansion valve	2	Thermal expansion valve
Liquid line	5	
Suction line	4	
HP service valve	1	Located on the main liquid line
LP service valve	1	Located on the main suction line
HP sensor	1	Located on the main liquid line after the HP receiver

Leak flow rate calculation

Table 1.7 LFRs of MAC system B.

T (℃)	Saturation Pressure (kPa)	LFR (g/yr)
30	770	19.6 ± 1.2
40	1017	33.0 ± 2.0
50	13118	59.4 ± 3.6

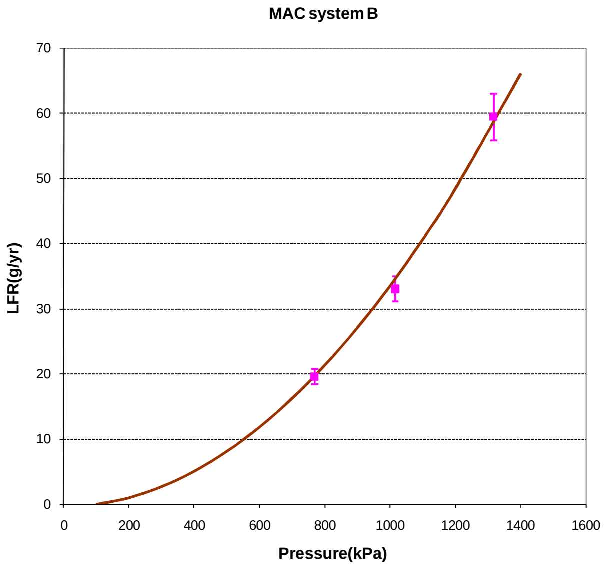


Figure 1.3 LFRs & Regression curve of MAC system B.

Table 1.8 Determination of the annual LFR of MAC system B taking into account CA population.

	Arcata	Bakersfield	Daggett	Fresno	Long Beach	Los Angeles	Sacramento	San Diego	San Francisco	Santa Maria	Total
Annual mean T(℃)	10.4	18.5	19.8	17.1	17.2	16.7	15.2	17.6	13 .1	12.9	
Saturation Pressure(kPa)	420	546	568	522	523	516	492	530	459	456	
K= 3.382E-05											
LFR(g/yr)	5.6	9.7	10.6	8.9	8.9	8.7	7.8	9.2	6.8	6.7	
Population	790525		4669274	2962948		12901515	3443421	2933929	5966569	2173073	35841254
% Population	2.2%		13.0%	8.3%		36.0%	9.6%	8.2%	16.6%	6.1%	100%
LFR%	0.1		1.4	0.7		3.1	0.8	0.7	1.1	0.4	**8.4**

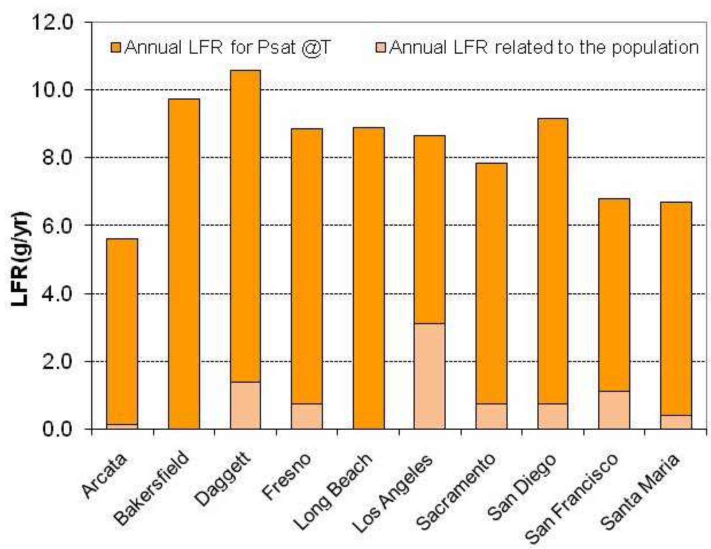


Figure 1.4 LFR variations taking the population into consideration.

MAC System B

1.2.3 MAC system C

System specifications

Table 1.9 System specifications.

Brand	MAC system C
Type	Pickup
Motorization	5.4 l
Vintage	2007
MAC system	Single evaporator
Nominal refrigerant charge	940 g

System design

Photo 1.4 Assembled MAC system C.

Table 1.10 List of components.

Components	Numbers of components	Comments
Compressor	1	
Condenser	1	
Evaporator	1	
LP receiver	1	
Expansion valve	1	Orifice tube
Discharge line	1	
Liquid line	1	
Suction line	2	
HP service valve	1	Located on the discharge line
LP service valve	1	Located on the suction line
HP sensor	1	Located on the suction line
LP sensor	1	Located on the LP receiver

Leak flow rate calculation

Table 1.11 LFRs of MAC system C.

T (℃)	Saturation Pressure (kPa)	LFR (g/yr)
30	770	13.9 ± 0.8
40	1017	21.7 ± 1.3
50	13118	35.4 ± 2.1

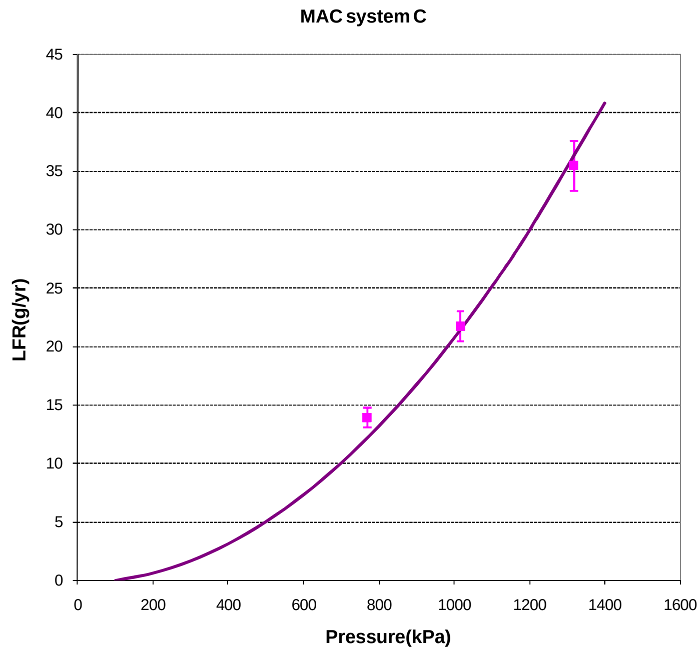


Figure 1.5 LFRs & Regression curve of MAC system C.

Table 1.12 Determination of the annual LFR of MAC system C taking into account CA population.

	Arcata	Bakersfield	Daggett	Fresno	Long Beach	Los Angeles	Sacramento	San Diego	San Francisco	Santa Maria	Total
Annual mean T(℃)	10.4	18.5	19.8	17.1	17.2	16.7	15.2	17.6	13 .1	12.9	
Saturation Pressure(kPa)	420	546	568	522	523	516	492	530	459	456	
K= 2.093E-05											
LFR(g/yr)	3.5	6.0	6.5	5.5	5.5	5.4	4.9	5.7	4.2	4.1	
Population	790525		4669274	2962948		12901515	3443421	2933929	5966569	2173073	35841254
% Population	2.2%		13.0%	8.3%		36.0%	9.6%	8.2%	16.6%	6.1%	100%
LFR%	0.1		0.9	0.5		1.9	0.5	0.5	0.7	0.3	5.2

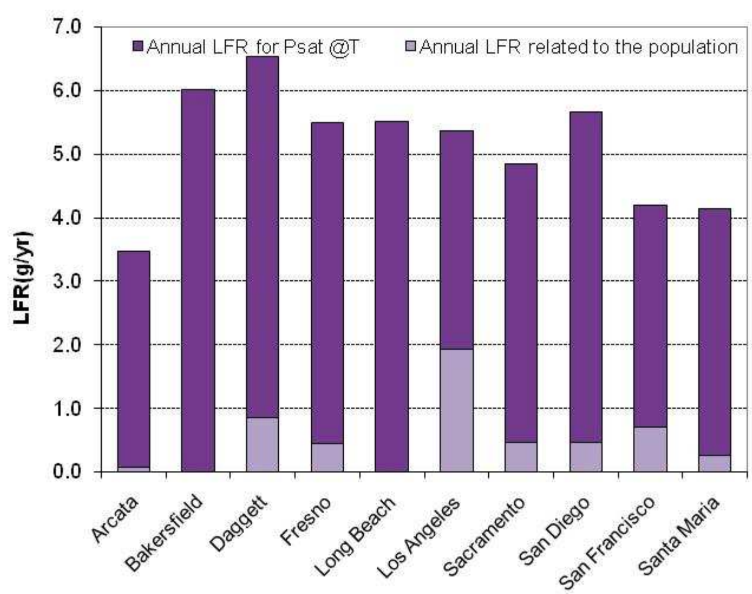


Figure 1.6 LFR variations taking the population into consideration.

MAC System C

1.2.4 MAC system D

System specifications

Table 1.13 System specifications.

Brand	MAC system D
Type	Family car
Motorization	2.4 l
Vintage	2006
MAC system	Single evaporator
Nominal refrigerant charge	650 g

System design

Photo 1.5 Assembled MAC system D.

Table 1.14 List of components.

Components	Numbers of components	Comments
Compressor	1	
Condenser	1	
Evaporator	1	
Expansion valve	1	Thermal expansion valve
LP liquid receiver	1	
Liquid line	3	
Suction line	2	
HP service valve	1	Located on the liquid line 2
LP service valve	1	Located on the suction line 1
HP sensor	1	Located on the liquid line 2

Leak flow rate calculation

Table 1.15 LFRs of MAC system D.

T (℃)	Saturation Pressure (kPa)	LFR (g/yr)
30	770	28.4 ± 1.7
40	1017	49.1 ± 2.9
50	13118	95.3 ± 5.7

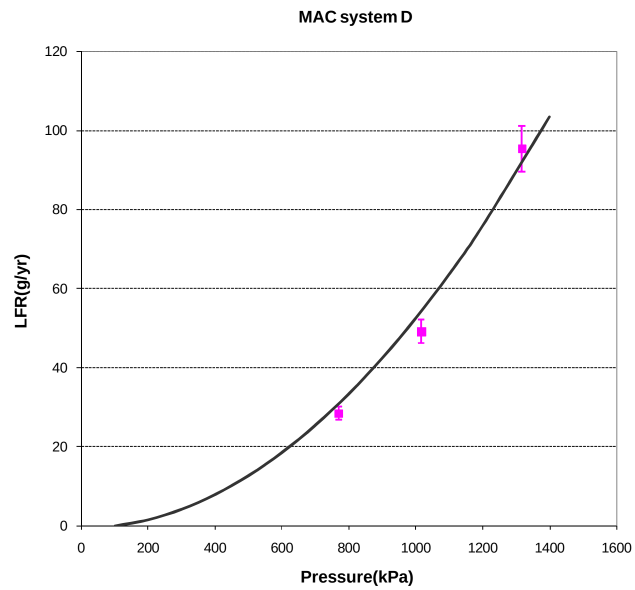


Figure 1.7 LFRs & Regression curve of MAC system D.

Table 1.16 Determination of the annual LFR of MAC system D taking into account CA population.

	Arcata	Bakers field	Daggett	Fresno	Long Beach	Los Angeles	Sacramento	San Diego	San Francisco	Santa Maria	
Annual mean T(℃)	10.4	18.5	19.8	17.1	17.2	16.7	15.2	17.6	13 .1	12.9	
Saturation Pressure(kPa)	420	546	568	522	523	516	492	530	459	456	**Total**
K= 5.29E-05											
LFR(g/yr)	8.8	15.2	16.5	13.9	13.9	13.6	12.3	14.3	10.6	10.5	
Population	790525		4669274	2962948		12901515	3443421	3E+06	5966569	2173073	35841254
% Population	2.2%		13.0%	8.3%		36.0%	9.6%	8.2%	16.6%	6.1%	100%
LFR%	0.2		2.2	1.1		4.9	1.2	1.2	1.8	0.6	**13.1**

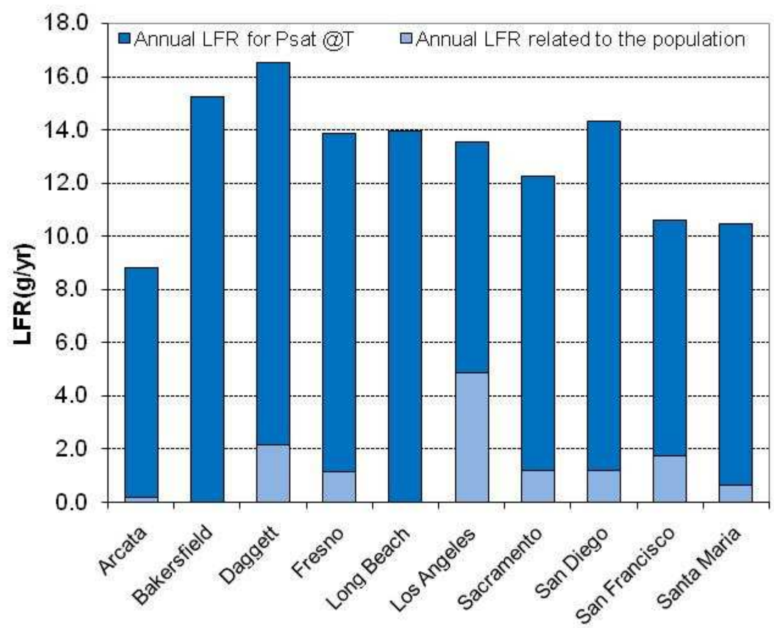


Figure 1.8 LFR variation taking the population into consideration.

MAC System D

1.2.5 MAC system E

System specifications

Table 1.17 System specifications.

Brand	MAC system E
Type	Family car
Motorization	-
Vintage	2006
MAC system	Single evaporator
Nominal refrigerant charge	800 g

System design

Photo 1.6 Assembled MAC system E.

Table 1.18: List of components.

Components	Numbers of components	Comments
Compressor	1	
Condenser	1	
Evaporator	1	
Expansion valve	1	Thermal expansion valve
Liquid line	2	
Suction line	2	
Discharge line	1	
HP service valve	1	Located on the liquid line
LP service valve	1	Located on the suction line
HP sensor	1	Located on the liquid line

Leak flow rate calculation

Table 1.19 LFRs of MAC system E.

T (℃)	Saturation Pressure (kPa)	LFR (g/yr)
30	770	24.2 ± 1.5
40	1017	45.3 ± 2.7
50	13118	82.3 ± 4.9

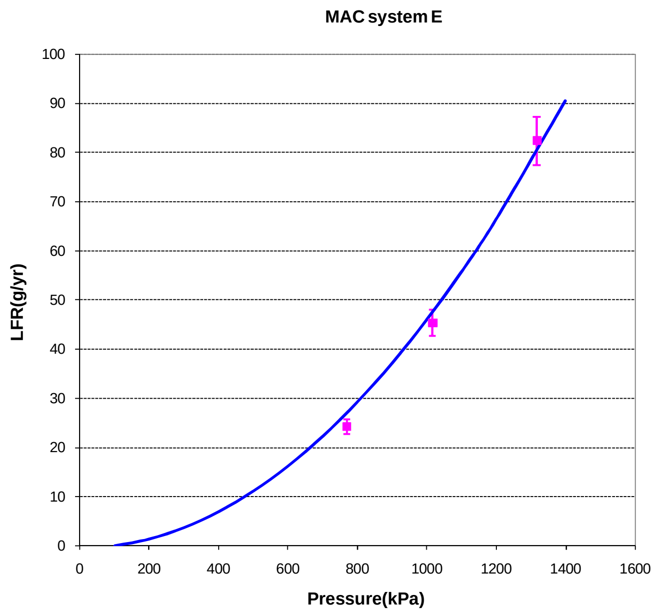


Figure 1.9 LFRs & Regression curve of MAC system E.

Table 1.20 Determination of the annual LFR of MAC system E taking into account CA population.

	Arcata	Bakersfield	Daggett	Fresno	Long Beach	Los Angeles	Sacramento	San Diego	San Francisco	Santa Maria	Total
Annual mean T(℃)	10.4	18.5	19.8	17.1	17.2	16.7	15.2	17.6	13 .1	12.9	
Saturation Pressure(kPa)	420	546	568	522	523	516	492	530	459	456	
K= 4.636E-05											
LFR(g/yr)	7.7	13.3	14.5	12.2	12.2	11.9	10.7	12.5	9.3	9.2	
Population	790525		4669274	2962948		12901515	3443421	2933929	5966569	2173073	35841254
% Population	2.2%		13.0%	8.3%		36.0%	9.6%	8.2%	16.6%	6.1%	100%
LFR%	0.2		1.9	1.0		4.3	1.0	1.0	1.5	0.6	**11.5**

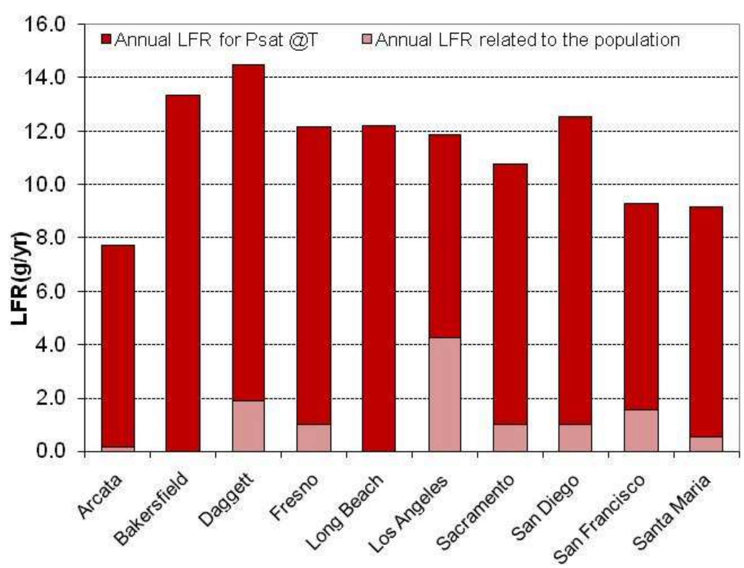


Figure 1.10 LFR variation taking the population into consideration.

MAC System E

1.3 Conclusion

The annual leak flow rate of a specified zone is related to its saturation temperature and saturation pressure as well as to the population. It is remarkable that the annual leak flow rate is more dependent on the population than temperature (see Figures 1.11 and 1.12). With 36% of California's population, the annual LFR in Los Angeles represents 37% of California's LFR, even though its average annual temperature is 16℃.

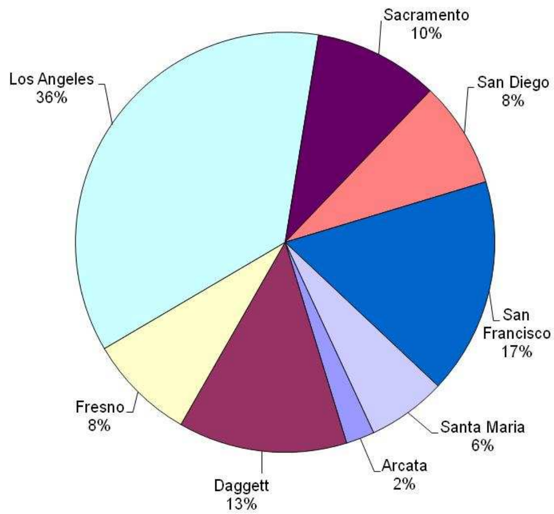


Figure 1.11 Population distribution.

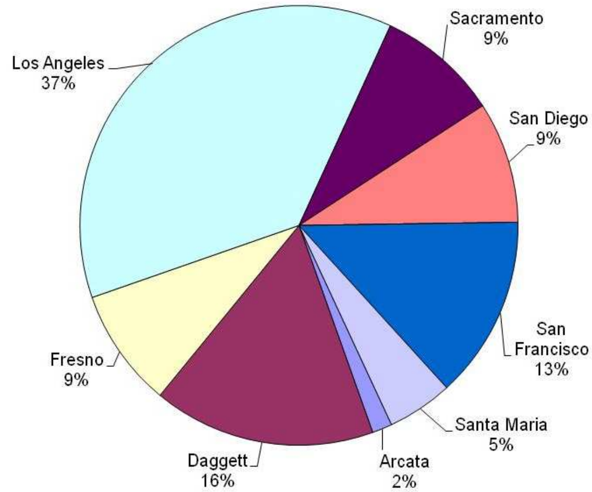


Figure 1.12 Annual LFR distribution as a function of population and temperature zones.

System	K	LFR@Temp
A	2.536E-05	6.3
B	3.382E-05	8.4
C	2.093E-05	5.2
D	5.295E-05	13.1
E	4.636E-05	11.5

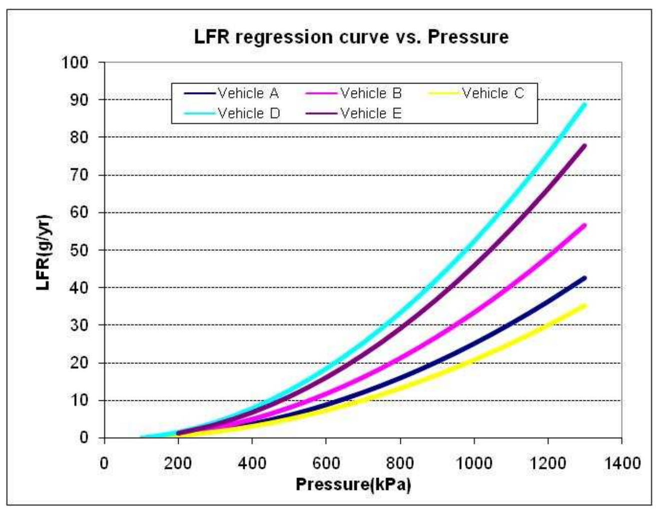
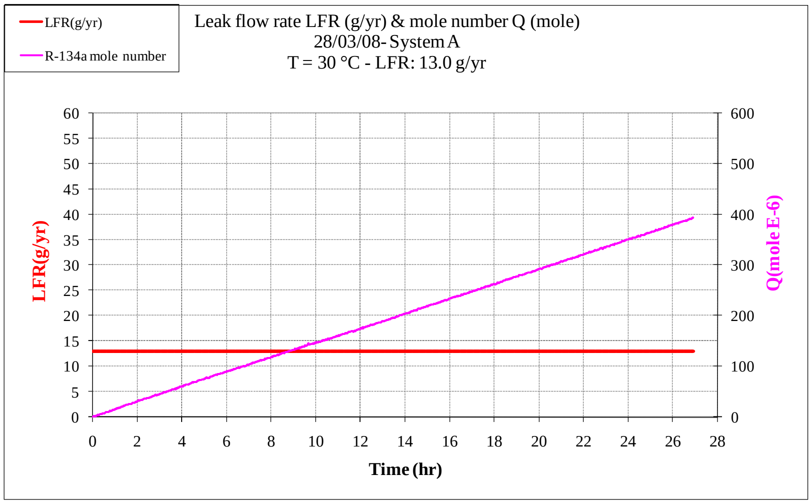


Figure 1.13 Vehicle annual LFR as a function of the pressure.

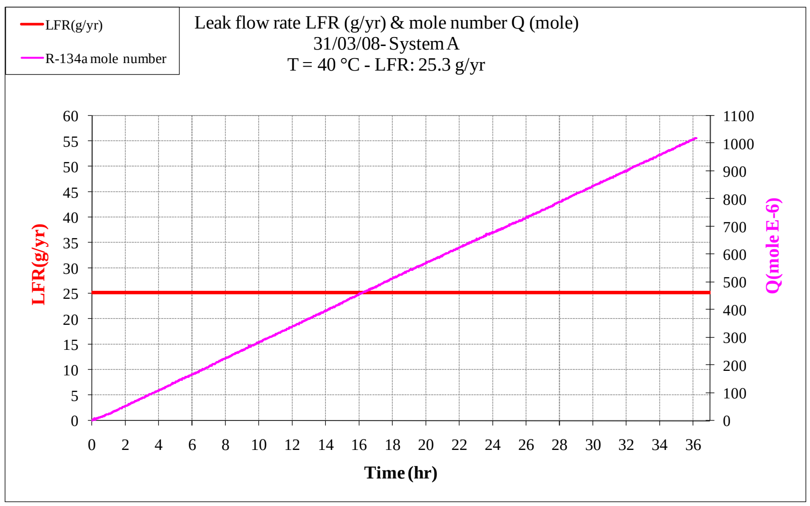
Another major conclusion can be drawn: the LFRs of MAC systems mounted on the five most sold cars in California confirm that the automotive industry is a global one, because the LFRs measured are in the same range as those measured in Europe or in Japan on MAC systems of fleet of vehicles and in laboratories: the average annual LFR of new systems is around 10 g/yr ±4 and possibly higher for some double evaporator systems. If this LFR were to be maintained, then MVACs would not need re-charging during the life of the vehicle. This is not the case due to the large quantities of refrigerant sold for the servicing of the systems. In addition, ARB performed one study (Vincent et al.) in which the data indicated that most MVAC servicing occurs after 8 to 9 years of vehicle life. This study which included data from more than 12,500 vehicles estimated that the average LFR from MVAC systems is about 80 g/yr over the lifetime of the vehicles. Thus, the tightness of MVAC systems degrades over time probably due to a variety of factors including system operation, operating temperatures, and vibrations due to vehicle operation.

Appendix 1: Leak flow rate and mole number graph MAC system A

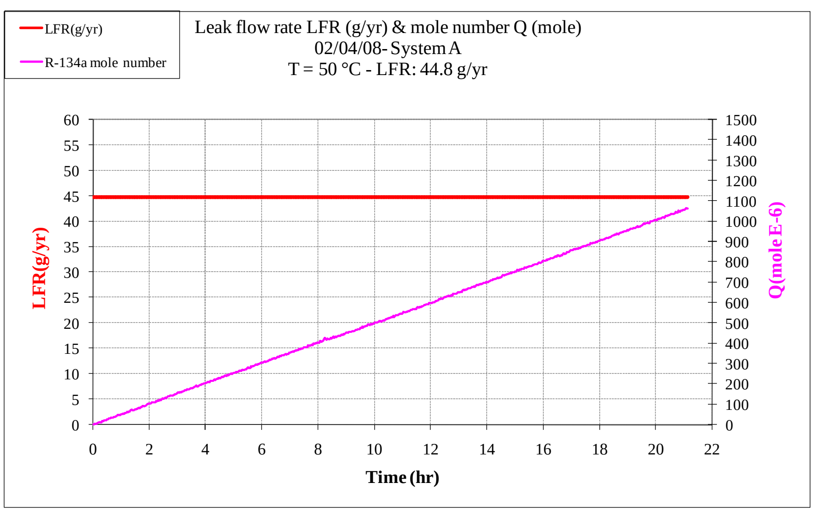
- **T=30℃**



- **T=40℃**

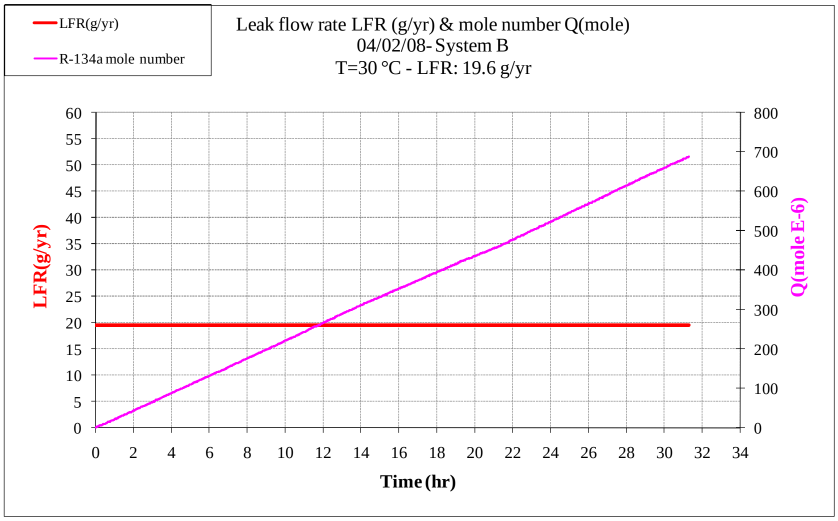


- **T=50℃**

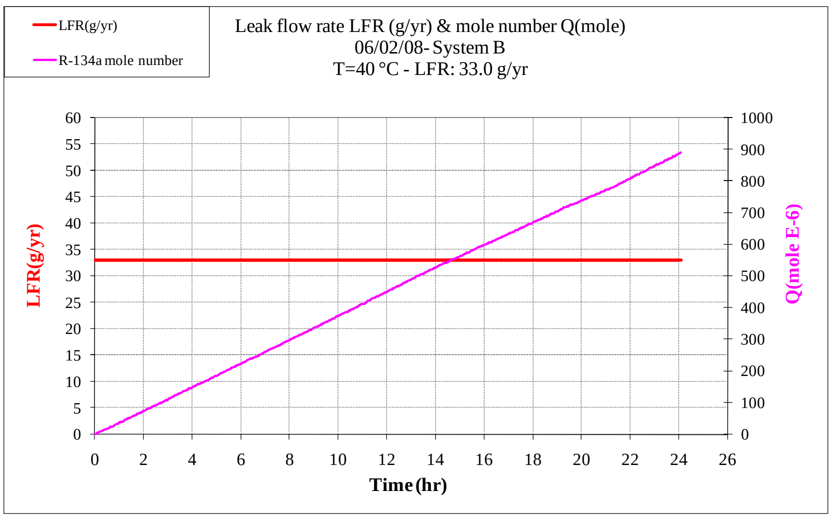


Appendix 2: Leak flow rate and mole number graph MAC system B

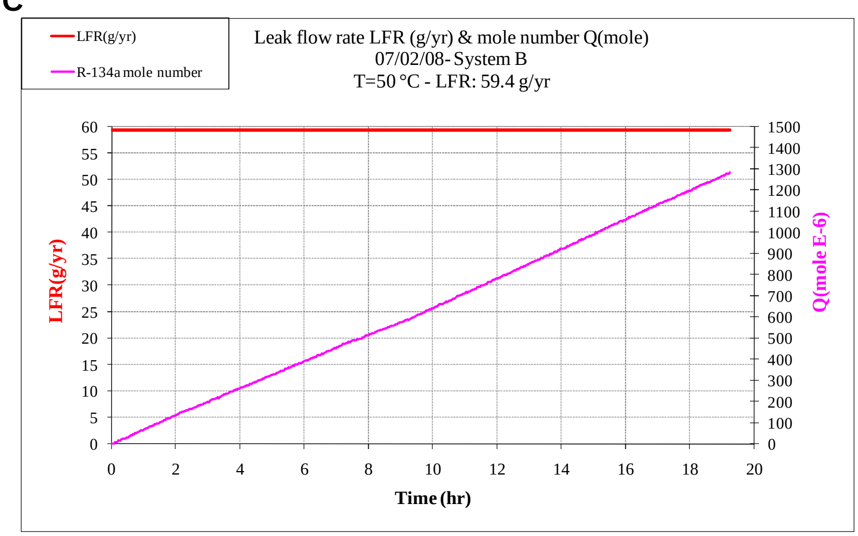
- **T=30℃**



- **T=40℃**

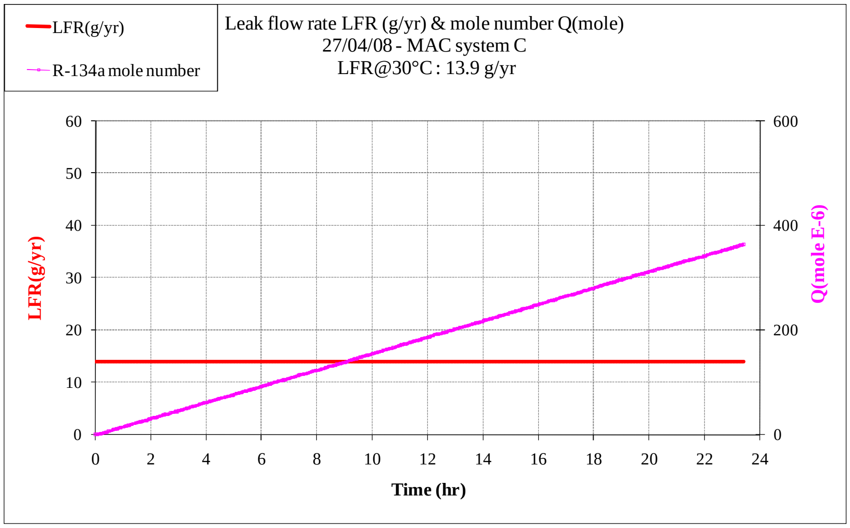


- **T=50℃**

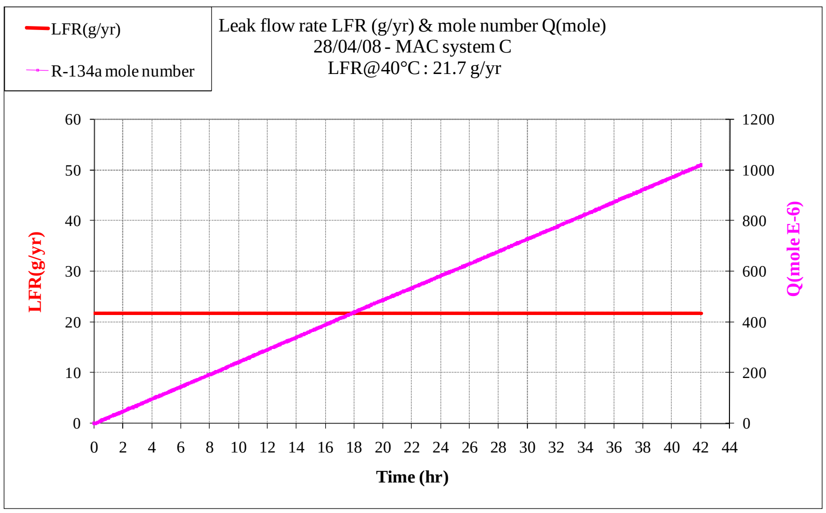


Appendix 3: Leak flow rate and mole number graph MAC system C

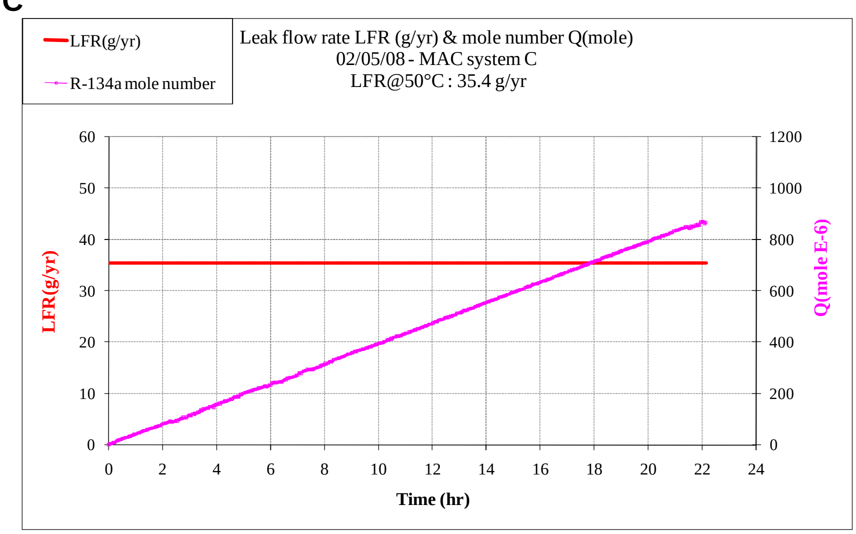
- **T=30℃**



- **T=40℃**

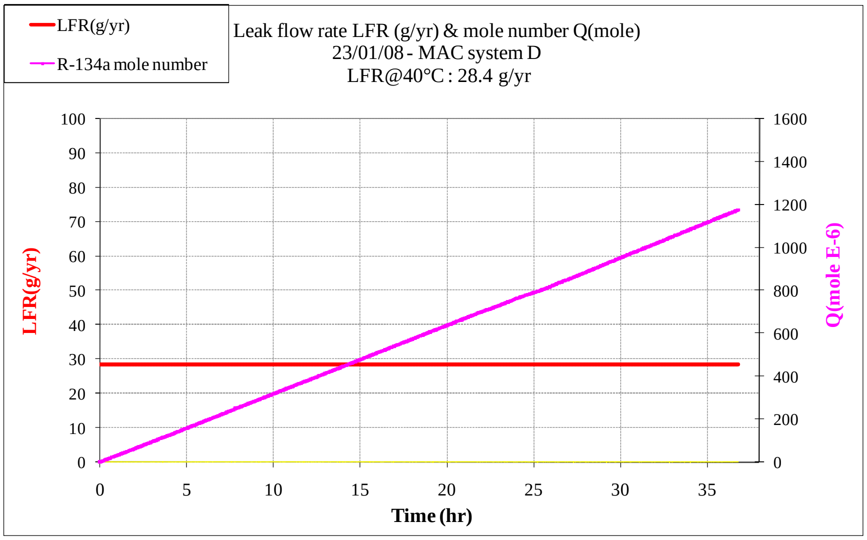


- **T=50℃**

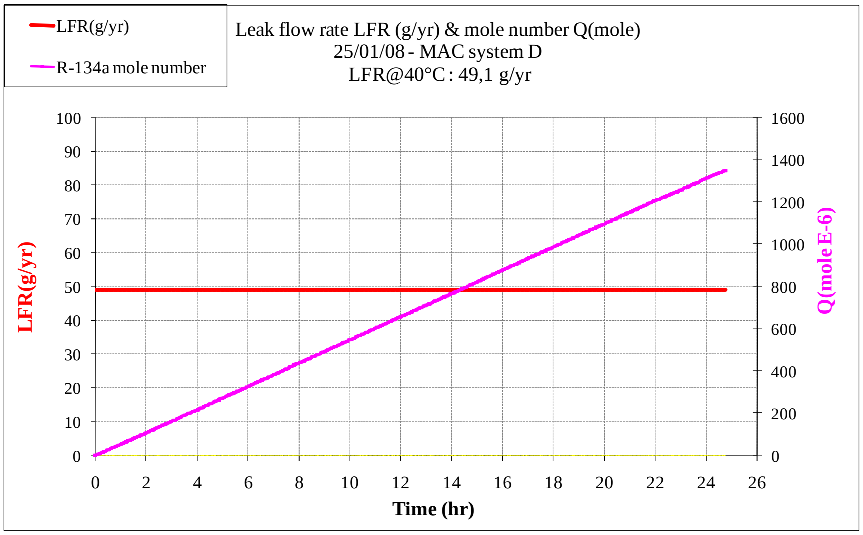


Appendix 4: Leak flow rate and mole number graph MAC system D

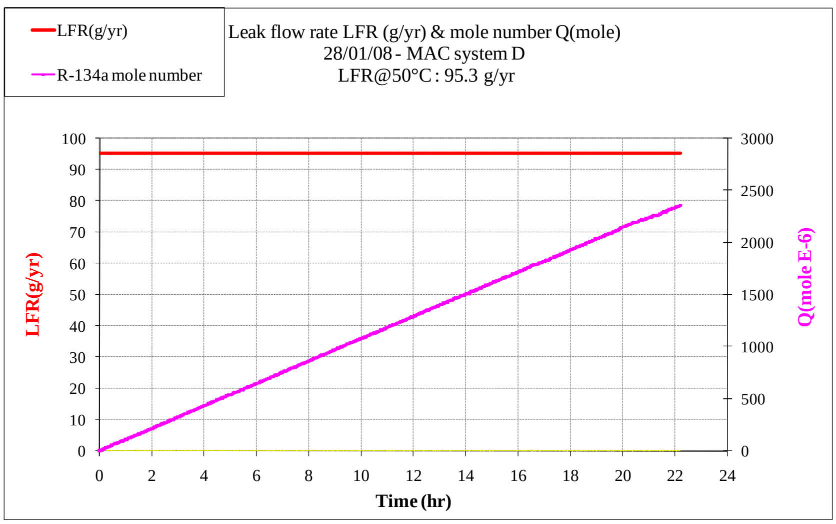
- **T=30℃**



- **T=40℃**

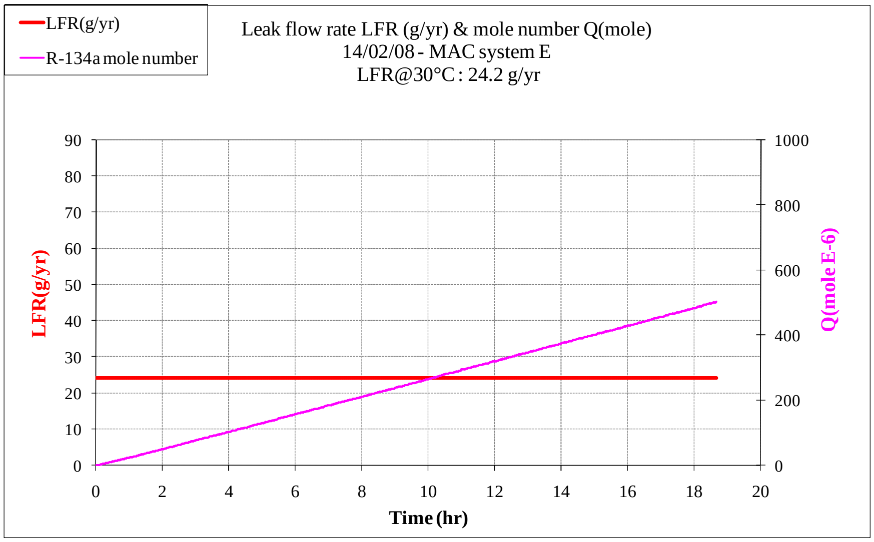


- **T=50℃**

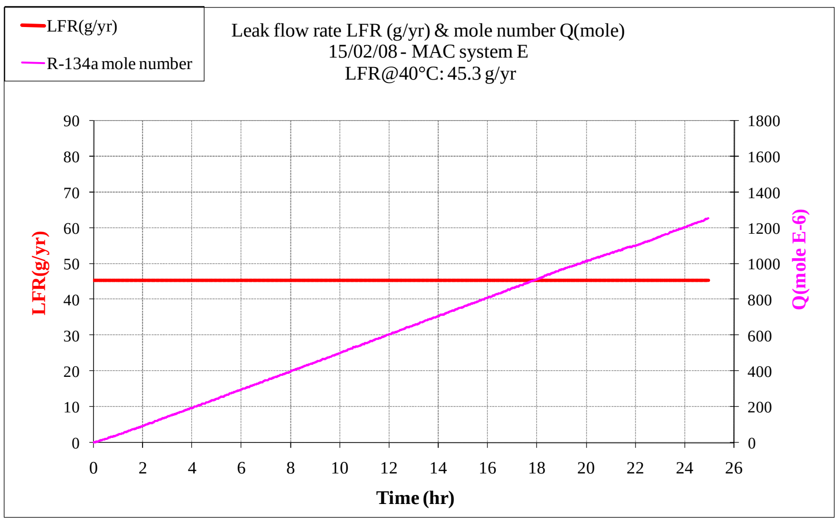


Appendix 5: Leak flow rate and mole number graph MAC system E

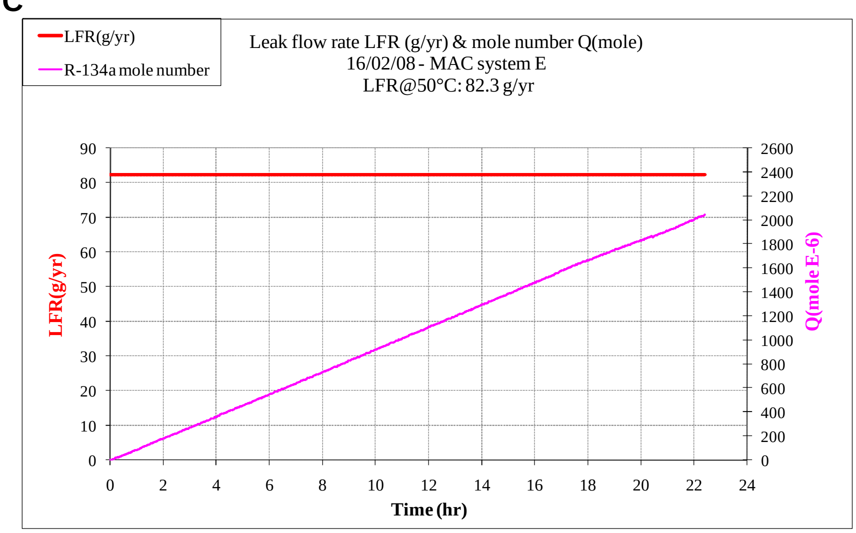
- **T=30°C**



- **T=40°C**



- **T=50°C**



2. Analysis of current recharge by non professionals in California

2.1 Introduction

In order to evaluate the potential impact of HFC-134a emissions from non-professional servicing of MVAC systems, the ARB commissioned the CEP for a study including field tests in order to measure refrigerant emissions during 50 real refilling operations of MVAC systems.

The research project aims to identify emission rates due to non-professional servicing as compared to professional servicing based on servicing operating modes observed in the State of California.

Given enough time, a leaky MVAC system will release its entire refrigerant content to the atmosphere if the refrigerant leak is significant. The MVAC system leak flow rates imply one or more recharge(s) of the MVAC system during the vehicle's lifetime. During a charging process, refrigerant emissions could be classified into two categories:

- Direct emissions due to leaks from disposable containers (cans or cylinders), hoses, and fittings; or
- Heel emissions due to the refrigerant remaining in the disposable containers after charging.

Section 2.2 describes the disposable small cans available on the Californian market, including contents, prices, and types. Leaks before and after use of some can samples have been measured in the laboratory and are presented in Section 4.2.

Analysis of current recharge by non-professionals, Do-It-Yourselfers (DIYers), in California is presented in Section 2.3. The know-how and the expert skills have to be taken into account when drawing conclusions. Two sampling groups of non-professionals are considered and classified based on their qualifications. Analyses will be made for each sampling group as well as for the non-professional DIYers who have recharged different MVAC systems.

2.2 Small cans: description and leak test results

2.2.1 Small can description

Two categories of small cans (SC) are available on the Californian market:

- Screwed and Perforated Cans (S&P) (Photo 2.1)
- Cans equipped with a valve and an optional pressure gauge (V-type) (Photo 2.2)

S&P cans are available in different capacities: 12, 13, 14, 18, and 19 oz. V-type cans are available in 14 oz and 19 oz capacities.

Photo 2.1 S&P Can

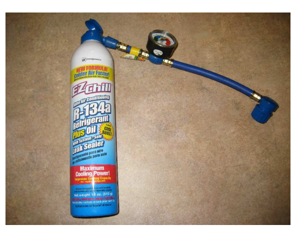


Photo 2.2 Can equipped with a valve and pressure gauge.


Photo 2.3 Re-usable charging kit for S&P small cans.

S&P cans are connected to a charging kit. Photo 2.3 presents an example of a charging kit. This charging kit is usually composed of:

- Can tap: perforating valve, with a screw fitting
- Flexible hose
- Service valve adaptor: low-pressure fitting
- Pressure gauge (optional)

Table 2.1 lists a large variety of small cans available on the Californian market, their type, content, market price, and online price. A list of small cans and their characteristics is presented in Annex A.

Table 2.1 Small cans details.

SC brand name	Model	Type	Content	Price Kragen	Price Kragen 2	Price Net www.partsamerica.com/
Quest	Normal	S&P	12 oz		7.99 $	
Quest	UV	S&P	12 oz		11.99 $	
Quest	Stop Leak	S&P	12 oz		11.99 $	
Quest	Sub Zero Polar Bear	S&P + reusable kit	19 oz	28,99 $	25.99 $	$24.99
Johnsen		S&P	12 oz	7,99 $	8.99 $	$8.99
Johnsen	UV Dye	S&P	12 oz		14.99 $	
Interdynamics	EZ Chill	Valve equipped	14 oz	21,99 $	17.99 $	
Interdynamics	Arctic Freeze	S&P	13 oz		13.99 $	$12.99
Interdynamics	Arctic Freeze	Valve equipped + gauge	12 oz		39.99 $	
Interdynamics	Arctic Freeze	Valve equipped	19 oz			$32.99
Interdynamics	Arctic Freeze with Reusable Trigger	Valve equipped	14 oz			$26.99
Interdynamics	EZ Chill+hose	Valve equipped			28.99 $	
Interdynamics	EZ Chill Measure/Recharge Kit	Valve equipped + gauge	19 oz			$24.99
Interdynamics	Arctic Freeze	S&P	18 oz			$27.99

To conclude, the S&P cans are cheaper than the V-type cans The S&P price varies according to the refrigerant content and the brand name. In order to save money people prefer to buy the charging kit once and then reuse it with S&P cans. It should be noted that the S&Ps are dominant (nearly 90% of the market, as assessed by several dealers) for two reasons: the more knowledgeable DIYers buy S&Ps due to the ease of use; less knowledgeable, but price-oriented DIYers also choose S&Ps.

2.3 Analysis of recharge by do-it-yourselfers (DIYers)

The aim of this section is to determine refrigerant emissions when a MVAC is charged by a DIYer. When charging their own car, a DIYer releases direct and indirect refrigerant emissions into the atmosphere. Direct emissions are those emitted during the charging process (leaks from the hose, can tap, and service valve adaptor). Indirect emissions, known as “heel emissions”, are refrigerant remaining in the can after the DIYer has disconnected the service valve adaptor. If the kit is leaking, sooner or later the refrigerant remaining in the can will be released. An operating procedure needs to be developed in order to assess the different refrigerant emissions and the effective refrigerant mass charged in the MVAC.

2.3.1 Operating procedure for emission assessment

The operating procedure used to evaluate refrigerant emissions was carried out according to the following method described below:

- The CEP team performs an initial refrigerant recovery. The refrigerant charge of the MAC system is recovered (and weighed) in order to evaluate the efficiency of the charge operation made by the SCU (small can user).
- The CEP team partially charges the AC loop (typically 1/3 of the original charge), in order to perform the charging process under realistic conditions: the pressure is the R-134a saturating pressure.
  Note: If the system is evacuated and maintained under a relative vacuum, the charge with small cans is not representative of the usual use.
- Before the beginning of the SCU operation, different types of small cans are displayed to the individual. The SCU is free to choose one, or select the type that he usually uses for charging the AC system.
- The SCU proceeds in charging his AC system. He is free to use the number of small cans he wants. The CEP personnel take mental notes of the operation steps. After the operation is complete, the description is written on a dedicated field report.
- The CEP evaluates the refrigerant emissions during the charging process as well as the can heels. Can heels are measured by weighing the can before charging and after charging, and before the de-connection from the service valve. When the can cannot be weighed because the SCU dismounts it right away, emissions are included in the operation.
- The SCU is interviewed on his usual practice with small cans (periodicity of use, etc.) and some advice is given.
- The CEP team recovers the refrigerant from the MAC system after the charging process and the effective refrigerant mass charged into the system is known by the difference.

2.3.2 Descriptions of the small can user sample

The number of DIYers participating in this study is 50. This includes 5 persons who have been interviewed, but who have not performed the charge. They have answered the questions describing what they usually do for charging. The other 45 persons performed the charging procedure, either on their own vehicles or on the CEP cars. The 50-person sample is divided into two sampling groups. The first one takes into account the 30 cases presented in the first intermediate report (October 2007). The second sampling group gathers the remaining 20 cases done after the first report was presented. The second sampling group is comprised of persons who are relatively familiar with small cans.

Conclusions are consequently drawn for the two sampling groups as well as for the overall sample. Conclusions are intentionally divided into three groups in order to take into account the effect that experience and knowledge has on the refrigerant release.

Sample 1 This sample includes 30 persons who have been interviewed, observed doing the charging process (5 persons), and those who performed the charging procedure, either on their own vehicles or on the CEP cars (25 persons). The 25 cases include:

- 16 persons (all not SC experts), who have charged the MAC system on their own vehicles,
- 6 others persons, who have made the refrigerant charge of the CEP rental car (Chevrolet), and,
- 3 others who have made the refrigerant charge on a 1990 Cadillac Deville purchased by CEP.

Sample 2 This sample includes 20 cases where the charging process was made on a 1999 Mitsubishi Montero owned by CEP. The CEP team asked for help from persons near auto-parts stores due to the malfunctioning of the Mitsubishi MVAC system. 17 persons performed the operation, while 3 people told the CEP staff how to re-charge the air conditioner. The CEP team performs exactly what the person asks him to do.

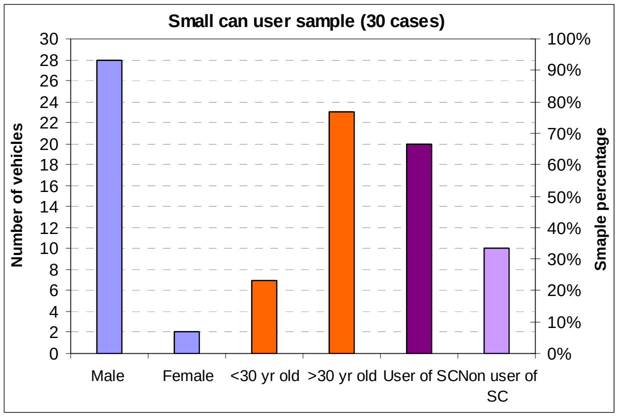


Figure 2.1 Small can users - Sample 1.

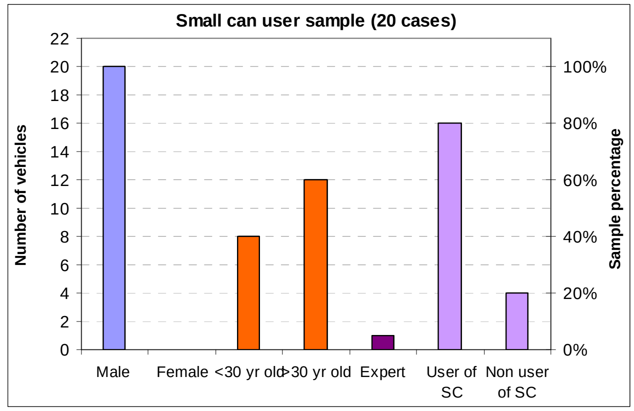


Figure 2.2 Small can users - Sample 2

The first sample of small can users are mainly composed of males. Two saleswomen working at the Kragen auto-parts store helped the CEP team to fill their car while simulating a defective AC. 23 persons are older than 30, and 5 are familiar with car self-servicing, but they are not experts in air conditioning (see Figure 2.1). 67% of the 30 persons declared that they had already used small cans on their car air conditioner. The others have never used small cans before, but they were interested either for curiosity or for saving money by avoiding professional service.

For the second sample, all persons are men, among whom 12 are older than 30. 80% of the 20 persons acknowledged the use of SC. They had made the charging procedure on their own car or on a family member car before or, at least, they watched someone doing it before. The second sample comprises a large proportion of users familiar with SCs compared to the first sample (see Figure 2.2).

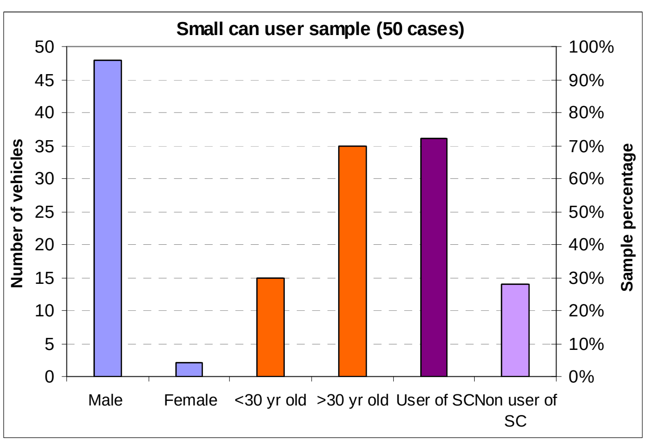


Figure 2.3 Small can users – All 50 cases

SC: Small Cans
SCU: Small Can Users

Now, considering the whole sample of 50 persons, more than 72% of the sample has used a small can before (see Figure 2.3). 40% are familiar with car self-servicing, meaning that they know how to proceed in recharging the MVAC (nevertheless they can sometimes make wrong operations).

2.3.3 Vehicle analysis

Figure 2.4 illustrates the car vintage of the 30 cases studied in the first sample. Five vehicles were originally filled with R-12 (vintage 1990 and 1991), but the retrofit to R-134a had been done previously, and the AC loop was equipped with an R-134a fitting when the charge with the small can had been done. The 5 cases on retrofitted R-12 vehicles included the three refrigerant chargings of the CEP Cadillac. The CEP rental car (Chevrolet) has been used 8 times (2 times for interviews and observing people helping the CEP team, and 6 times for a charging procedure). The Cadillac is used three times for the charging process.

The 20 cases in Sample 2 were performed on the 1999 Mitsubishi Montero.

The overall number of recharging procedures made is 45, distributed as follows:

- 16 times on different vehicles owned by the DIYers,
- 6 times on the CEP rental car (Chevrolet),
- 3 times on the CEP Cadillac Deville and
- 20 times on the CEP Mitsubishi Montero.

Car vintage of the 16 vehicles owned by the DIYers

As shown on Figure 2.4, most cars were less than 10-years old. When looking at Figures 2.4 and 2.5, one may wonder if the older car had the lower refrigerant charge. In fact, the distribution of low refrigerant charges remaining in the MAC system is not related to the car vintage.

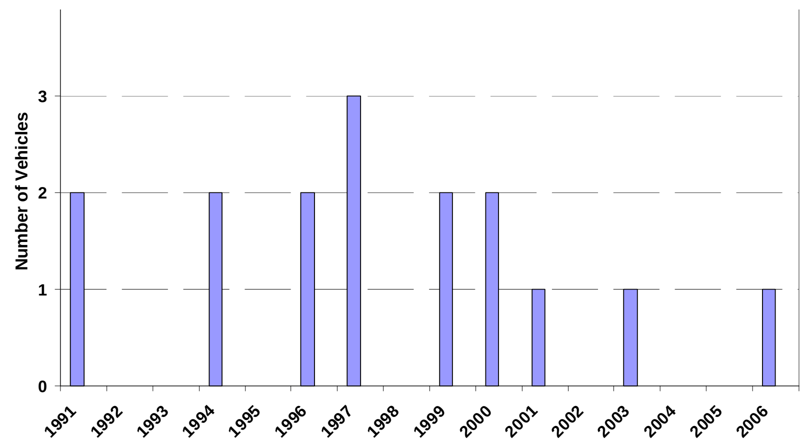


Figure 2.4 Car vintage for the 16 vehicles owned by the DIYers.

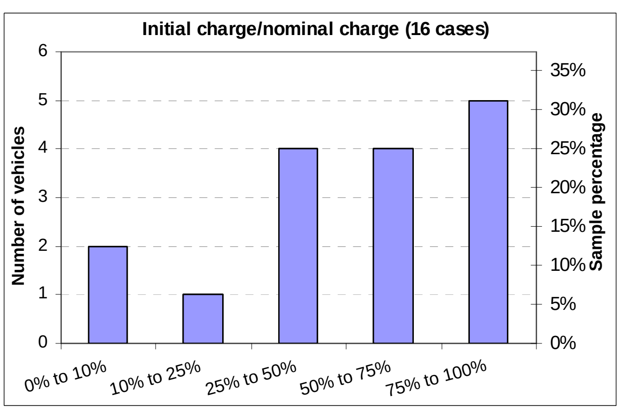


Figure 2.5 Initial charge / nominal charge before the SC charging.

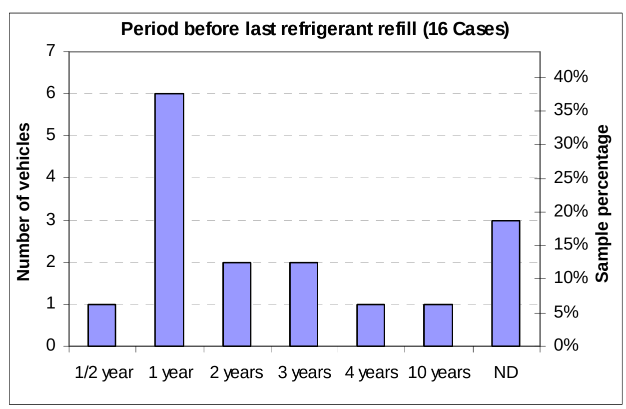


Figure 2.6 Periodicity of small can use.

ND: Not Defined

Figure 2.5 shows the initial charge of each vehicle, measured before the charging process with a small can. It indicates the number of vehicles (left scale) and the percentage on the sample (right scale). They are classified in categories depending on their initial refrigerant content (x axis).

Two vehicles were nearly empty of refrigerant before the operation. One third of the sample had an initial refrigerant charge between 75% and 100% of the nominal charge. One quarter of the sample had their AC working with a charge between 50% to 75%. 45 % have their system either working very badly (25%) or not working at all (20%). Nearly 45% of the sample check their AC annually (see Figure 2.6). After the recovery, all AC systems have been evacuated and recharged with a partial charge (1/3 of the corresponding nominal charge).

2.3.4 Charging procedure evaluation

Choice of small can

DIYers have to choose the small can type they want. Most of them chose the "screwed and perforated" type. 77% and 80% chose the S&P type respectively for Samples 1 and 2 (see Figures 2.7 and 2.8). The 12-oz capacity can, the smallest available, is preferred to the others, representing nearly 64% of the overall sample (see Figure 2.9).

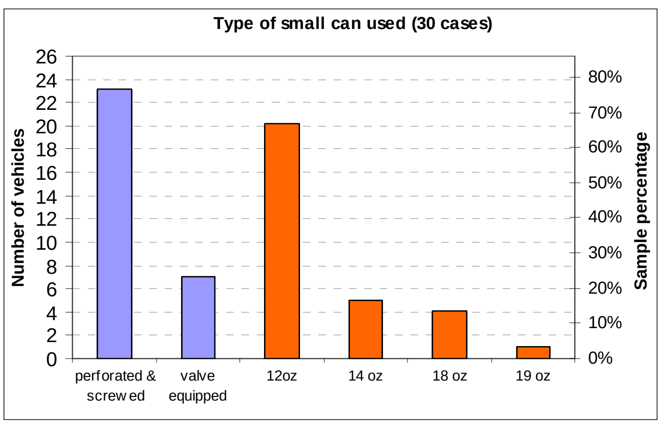


Figure 2.7 Type and capacity of small can chosen by the users (Sample 1).

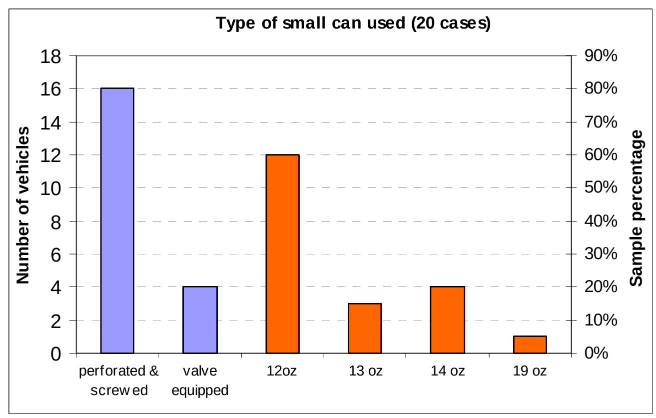


Figure 2.8 Type and capacity of small can chosen by the users (Sample 2).

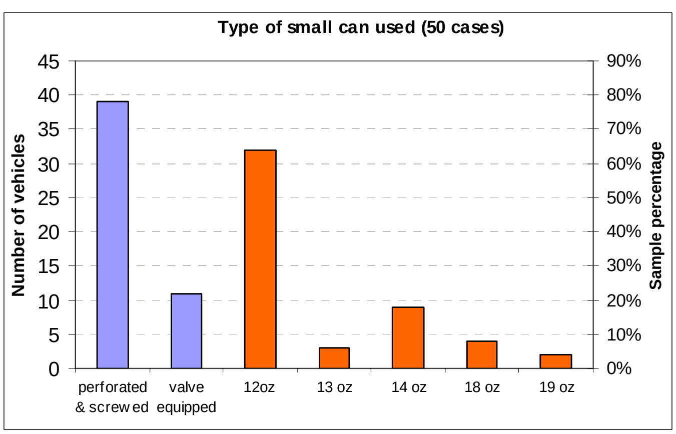


Figure 2.9 Type and capacity of small can chosen by the users (overall sample).

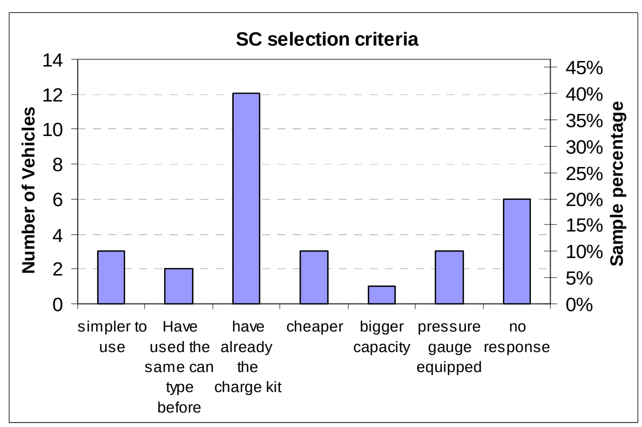


Figure 2.10 Criteria for small can type choice.

Figure 2.10 indicates criteria used by DIY individuals in selecting the type of container. The most frequent one is that the individual already possesses an S&P charging assembly and naturally selects an S&P-type container. Referred to in Table 1.1, the price of the valve-equipped can is two to three times higher than that of the S&P can. In addition if the SCU wants to use more than one can, he would prefer to buy the S&P with the reusable charging kit.

Based on the number of persons who had already performed the procedure on their own vehicles, 63% of small can users decided to recharge their AC because of lack of cooling performance (see Figure 2.11). This fact is consistent with the analysis of the refrigerant content (see Figure 2.5) before servicing: two third of the sample have an initial refrigerant content lower than 75% of the nominal charge. Nearly half of the fleet was below a 50% refrigerant nominal charge.

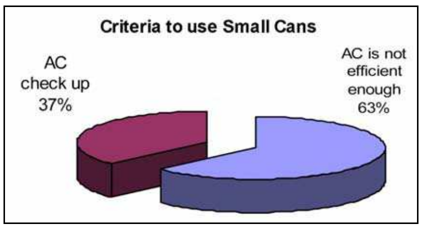


Figure 2.11 The reasons to use a small can.

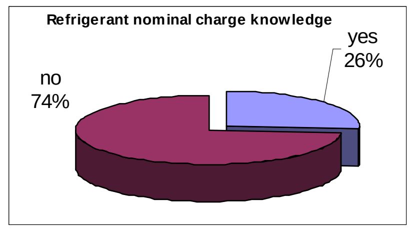


Figure 2.12 Knowledge of the AC nominal charge.

Only 26% of the small can users know the mass of refrigerant to be filled in their system (see Figure 2.12). Among the selection criteria announced by the DIYers, it is amazing that none of them relates the can capacity to the vehicle's original charge. All criteria that DIYers take into account are mentioned in Figure 2.10.

In fact, the can capacity should be an important criterion for the DIYer when choosing a SC because the can capacity is directly linked to the system nominal charge (announced by the manufacturer) and to the remaining AC system charge. A system whose nominal charge is 900 grams needs two or more 12-oz cans.

Indeed, the information and equipment available to DIYers are usually too limited to allow them to know how much refrigerant to add or when the system is fully charged. This lack of information can lead to the ineffective use of small cans as well as the inappropriate charging of the MVAC system.

Charging procedure

No instructions were given to small can users during their operation. They were observed and the facts and actions are reported on in Figures 2.13 to 2.15 respectively for the first, second, and overall samples.

Sample 1 people seem to be less familiar with SCs as compared to those of Sample 2. The following criteria verify this observation.

Reading instructions chart: Nearly 67% of people read the instructions in Sample 1 compared to 35% in Sample 2. Usually they think they already know what to do and many times do not read the instructions any more.

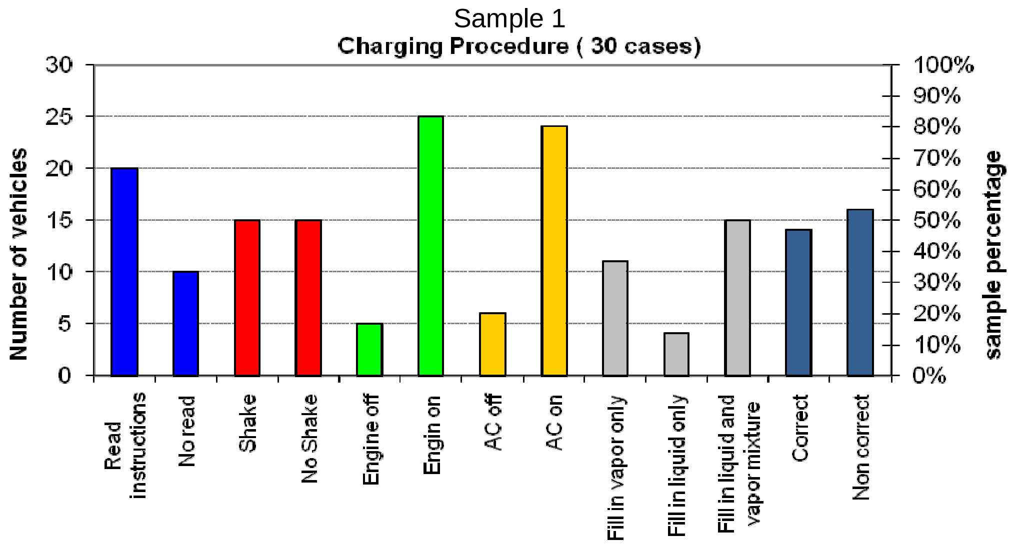


Figure 2.13 Report of facts and actions during the charging process of small can users (sample 1).

Engine on or off: several persons in Sample 1 did not turn on the engine (18%) or the AC system (20%) as shown in Figure 2.13. In contrast, all persons of Sample 2 did turn on the engine and the AC system (see Figure 2.14).

Shaking the can: 75% of Sample 2 shook the can during charging, while only 50% did in Sample1.

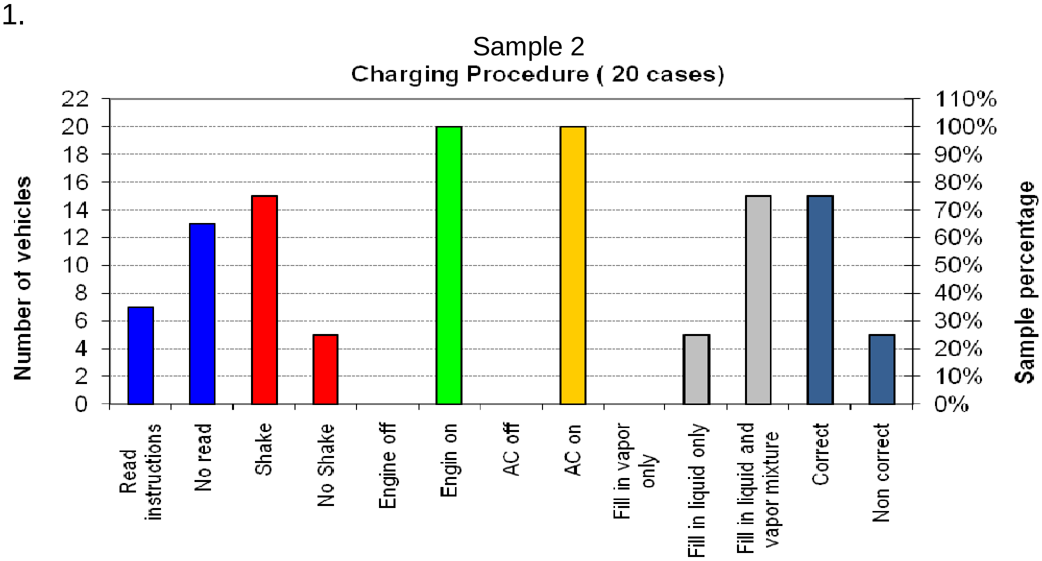


Figure 2.14 Report of facts and actions during the charging process of small can users (Sample 2).

Note: Nearly all SCUs when shaking the can were shaking it strongly. Some were shaking the can from the vertical to the horizontal position, and others were only shaking it with small amplitude (not moving it up to the horizontal position). In any case, the refrigerant charge is a two-phase flow.

Nevertheless, only 75% of Sample 2 correctly performed the procedure compared to 48% for Sample 1. These values reflect that the familiarity with SCs is not a sufficient condition to charge correctly.

Now, considering the overall sample, more than 58% proceeded correctly by turning on the engine and the AC, and shaking the can from horizontal to vertical positions in order to charge in both the liquid and vapor phases.

Note: When the loop is equipped with a suction line accumulator, charging in liquid phase is not dangerous for the compressor. But if there is a HP receiver associated with a thermal expansion valve (TxV), it could damage the compressor (liquid slugging).

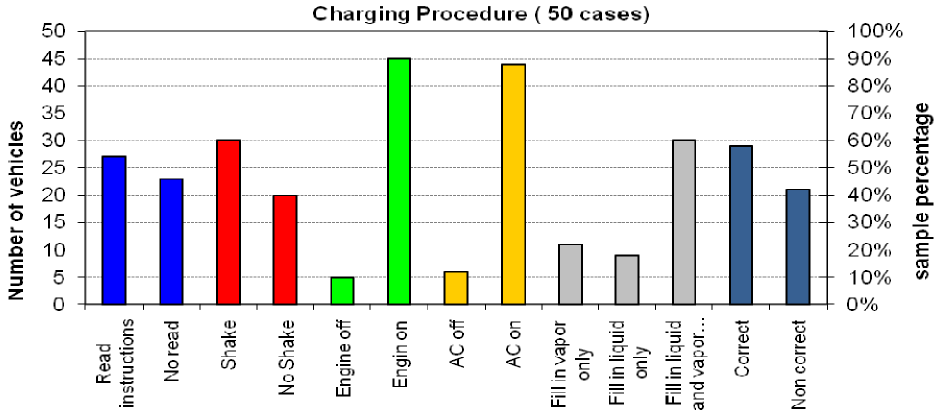


Figure 2.15 Report of facts and actions during the charging process of small can users (overall sample).

Criteria to stop charging the AC

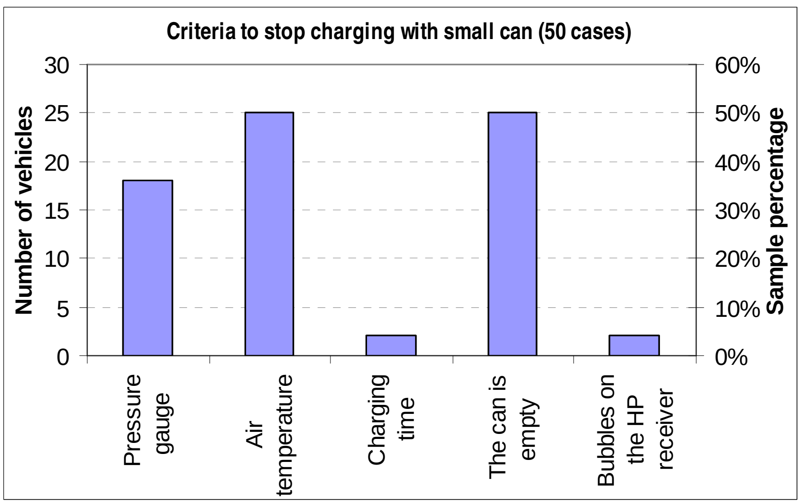


Figure 2.16 Diagnostic to stop charging.

Small can users were asked why they decided to stop charging the AC system. They could have answered one or two reasons (the number of answers is higher than the number of users). The air temperature at the AC outlet and verification by shaking the can to determine if liquid remained in the can were the most frequent reasons for stopping the recharge. Fifty percent measured the blown air temperature in the car to make sure the cooling was effective. The measure is subjective as they did not use any temperature sensor. Fifty percent stopped the charge when the can was empty. They would shake the can to see if it was empty; while others felt the can temperature: when the can was still cold, some refrigerant remained.

Note: Fifty percent answered that they stopped charging when the can was empty, but this fact does not mean that the cans were empty at the end of the different operations.

For cans equipped with a pressure gauge indicator, some of the people who read the instructions written on the cans followed the instruction that the charge is complete when the “Pressure ranges between 25 psi and 40 psi”. More than 35% of the answers are based on this criterion (see Figure 2.16). The pressure gauge indicates only the low-side system pressure showing different values and colors to indicate when the system is “undercharged”, “full”, or “overcharged” with refrigerant. But the system condition is dependent on more than just the amount of refrigerant in the MVAC system. The low-side pressure gauge indicates that refrigerant is circulating in the MVAC system and not the amount. A low-side gauge pressure of zero would indicate an empty system. Therefore, the kit gauge reading does not provide the information needed to determine the amount of refrigerant needed or the criteria to stop charging. On the contrary, wrong readings are delivered through the tag and the gauge.

Number of cans used to complete the refrigerant charge

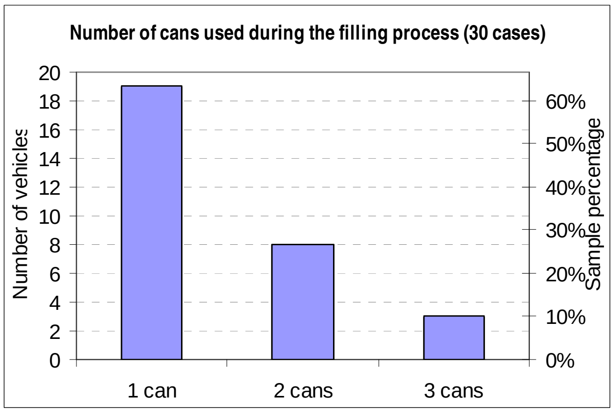


Figure 2.17 Cans used during charging (Sample 1).

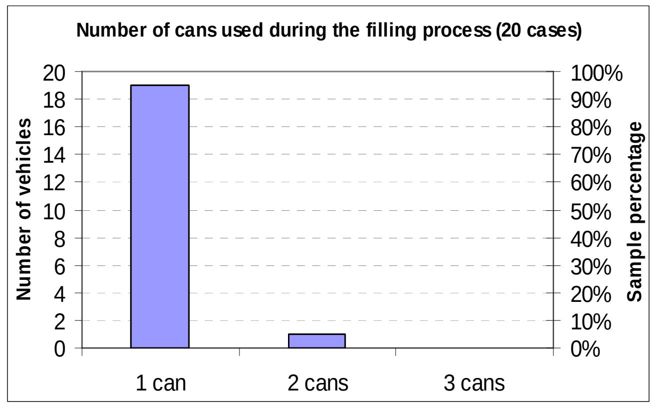


Figure 2.18 Cans used during charging (Sample 2).

The number of cans used during the charging process is directly related to the knowledge and the qualification of the user. In fact, without making a complete recovery, nobody can evaluate or estimate the quantity of refrigerant to be charged. Moreover, because the exact refrigerant mass that has been charged is also unknown, the number of cans is based on random issues. It may be that certain small can users are very cautious and use only a single can in order to avoid a major loss of refrigerant due to a significant leak or leaks. Another consideration would be over-charging which may damage the system.

Obviously, in Sample 1 more SCUs have used more cans than in Sample 2. 63% have used 1 can compared to 95% in Sample 2. Two of the three SCUs who used three cans did not proceed correctly. Most of small can users choose the smaller capacity cans (12 oz) (see Figure 2.9).

As shown in Figure 2.19, nearly 76% of operations were done with 1 can. 18% of operations were done with 2 cans and only 6% with 3 cans.

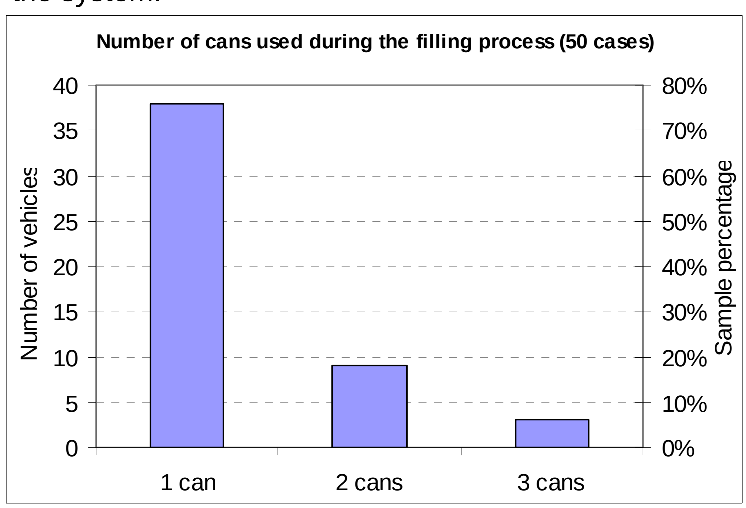


Figure 2.19 Cans used during charging (overall sample).

Refrigerant charging time

Here again, a DIYer familiar with SCs will recharge the system in 5 to 10 minutes. In fact, the charging time depends on both the filling mode (liquid or vapor) and on the can size. The regular time for charging a 12-oz small can, applying the correct procedure (continuous shaking), is 5 minutes. The time is longer when the can is not shaken and 15 minutes is insufficient to evaporate the complete content of the can in the upright position. Most cases that take longer than 20 minutes are done with more than 1 can.

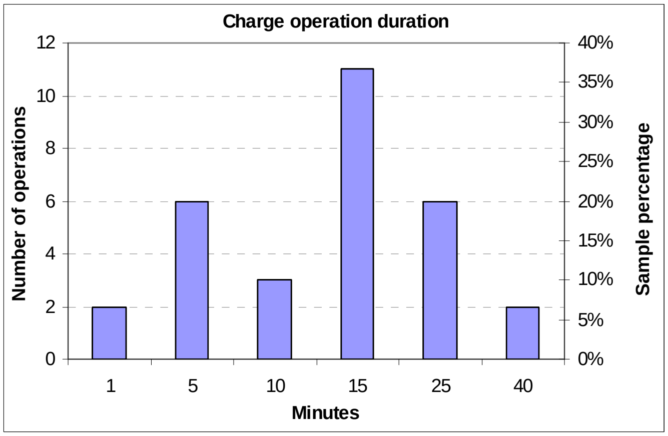


Figure 2.20 Refrigerant charging time (sample 1).

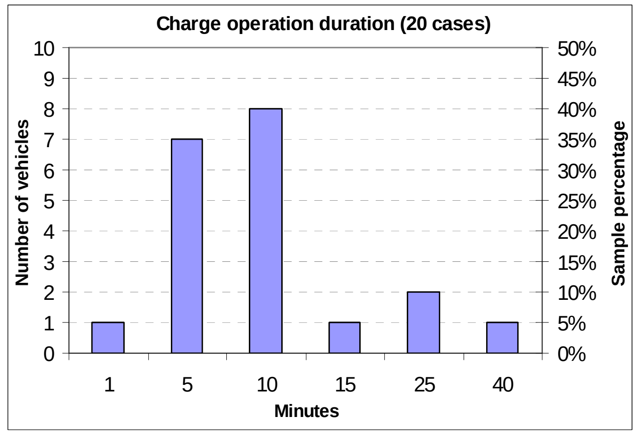


Figure 2.21 Refrigerant charging time (sample 2).

50% of Sample 1 SCUs charged the MVAC in the upright position (vapor phase only). This explains why the most frequent charging time is 15 minutes (see Figure 2.20). Only 30% of the operations took between 5 and 10 minutes.

In contrast, 75% of Sample 2 SCUs charged while shaking the can from vertical to horizontal positions. The most frequent charging times are 5 and 10 minutes, which is consistent (see Figure 2.21). 40% of operations took 10 minutes and 35% took 5 minutes.

Figures 2.20 and 2.21 indicate that two cases in Sample 1 and one case in Sample 2 completed, charging operations in only 1 minute. There are two reasons for the shortness of these operations:

- The SCU reads the pressure gauge indicator and stops charging because the pressure seems to be correct. The charge with a small can is limited to the pressure equilibrium. In this case most of the refrigerant remains in the can.
- The operator does not recognize how to proceed, so he stops the operation shortly after the beginning.

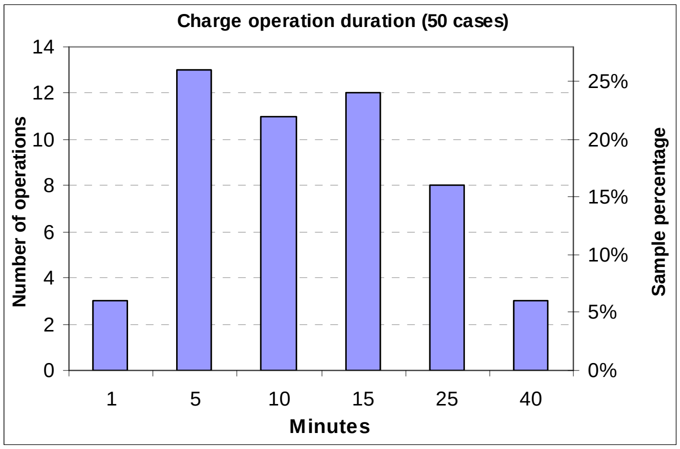


Figure 2.22 Refrigerant charging time (overall sample).

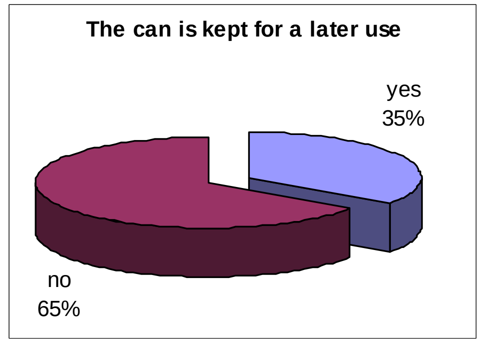


Figure 2.23 Part of people who keep the can after use.

Considering the charging time for the overall sample, nearly 50% took from 5 to 10 minutes. 5% took less than 1 minute and 5 % took more than 40 minutes. Cases where the charging process took 25 minutes are due to two reasons: vapor charging or more than one can has been charged.

After the charging operation, some refrigerant may remain in the can, and especially when the can capacity is large, or when the charging operation is performed in vapor phase. When the SCU is using a small can equipped with a valve, the can is reusable. But in the case of perforated cans, refrigerant is completely released when disconnecting the can. According to the field survey, two thirds of SCUs declare they will not keep the can after use (see Figure 2.23).

2.3.5 Refrigerant emissions associated with the use of small cans

Refrigerant emissions during the charging process

As presented in Section 2.3, the total number of vehicles tested was 45 including the 16 vehicles owned by the SCUs and 29 operations being done on the CEP cars.

The initial refrigerant content of the MAC system is known. The small can has been weighed before and after the charging process. The difference corresponds to the refrigerant mass released from the can: the first part is filled in the AC circuit; the second part is released during the charging process.

Once the refrigerant recovery is performed, the precise system charge using the small can is measured by difference with the known initial charge (1/3 of the original charge). The difference between the refrigerant contained in the can (initial weighing), and the refrigerant mass really filled in the MAC circuit is the refrigerant emission during the charging process, plus the refrigerant heel remaining in the can.

Figures 2.24 to 2.29 illustrate emissions in grams (g) due to servicing the can heel as well as the overall emissions for the overall sample (45 cases). Results corresponding to Samples 1 and 2 alone are presented separately in Annex B.

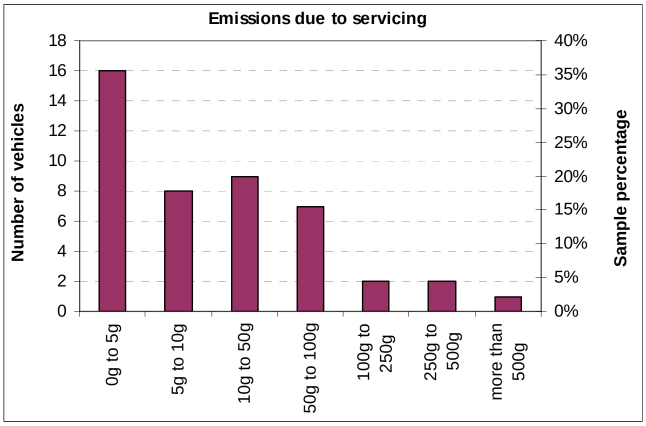


Figure 2.24 Number of vehicles as a function of emission range due to servicing (overall sample).

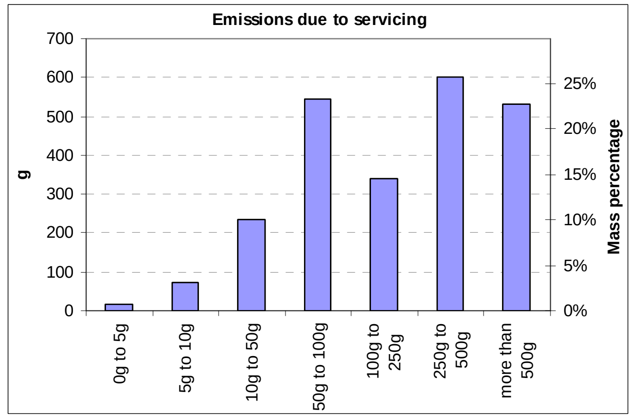


Figure 2.25 mass emission as a function of emission range due to servicing (overall sample).

Figure 2.24 presents the classification of operations as a function of emission range due to servicing for the overall sample composed of 45 operations. For 16 cases, representing 36% of the sample, small emissions have been observed: between 0 and 5 grams.

A few charging operations (five cases, or 10%) were very leaky and lead to massive releases of refrigerant (over 100 g):

- A great number of cans equipped with valves as well as some charging guns for S&P type (F1-13 illustrated in Section 1) are very leaky and are not very convenient to use. The valve is very leaky and frequently liquid refrigerant was released at the connection when the can is put upside down.
- When the operator is using 2 or more "screwed type" small cans, the release of refrigerant remaining in the first can be significant, if the can is not empty (filling in vapor phase, without shaking).

Figure 2.25 illustrates the emissions during servicing classified by emission ranges. Emissions from 0 to 10 g represent 54% of the sample. In contrast, these emissions represent only 4% of the total mass emitted during the charging process on a mass basis.

The major part of emissions (64%) is due to high releases, over 100 g, which represents only five of the sample cases. One non-correct operation done without care could release as much as 20 correct operations. 33% of the overall mass emissions range between 10 and 100 grams. Refrigerant emissions the during charging process, which lead to a mass loss higher than 50 g, represent nearly 86% in mass of the total refrigerant emissions, but only 26% of the sample. The total mass emitted due to servicing represents nearly 16% of the sum of the refrigerants charged inside AC systems.

Can heels

At the end of the charging process, the refrigerant remains inside the can (valve equipped) or is released to the atmosphere if the charging kit is unscrewed (in case of S&P cans). Depending on the charging process (shaking or not shaking the can, filling the AC system in the liquid or vapor phase) the refrigerant in the can heel is significant or not.

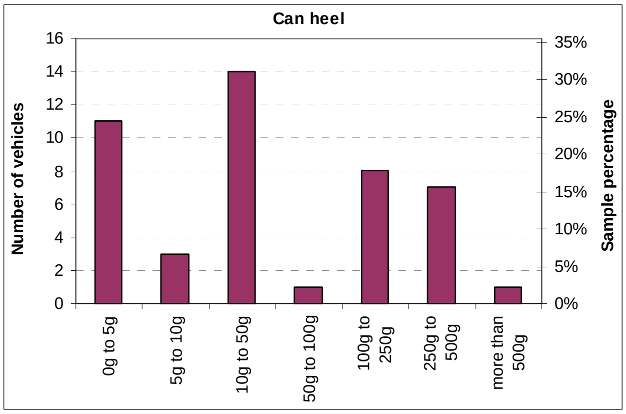


Figure 2.26 Number of vehicles as a function of can heel range (overall sample).

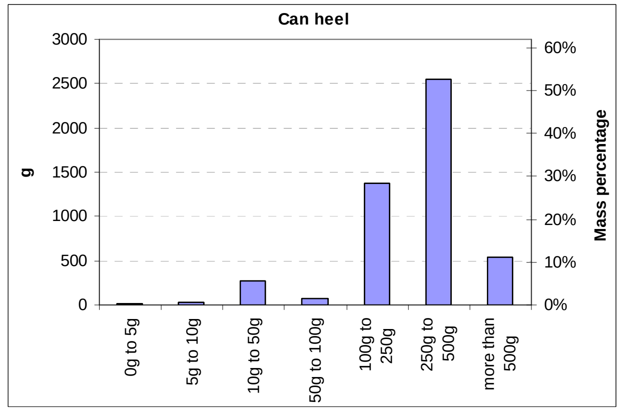


Figure 2.27 Mass emission as a function of can heel range (overall sample).

When the charging process is done correctly, the can is more likely empty at the end and the heel is low (between 0 to 10 g). This represents 31% of the operations that sensibly meet in the number of persons who did the operation correctly (32%).

62% of operations are done with the can heel lower than 50 g, which represent only 7% of the total heel (see Figure 2.27). 38% of operations are not properly done (can heel is larger than 50 g) but represent more than 90% of the overall can heel. The total heel resulting represents nearly 33% of the sum of the refrigerants filled inside AC systems.

Overall refrigerant emissions

Figures 2.28 and 2.29 illustrate the total refrigerant emissions coming from emissions due to servicing as well as from the can heels after charge, measured during the 45 operations performed by small can users.

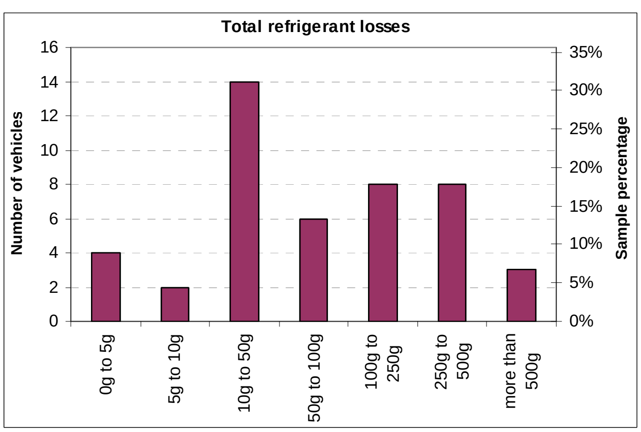


Figure 2.28 number of vehicles as a function of total refrigerant emissions (overall sample).

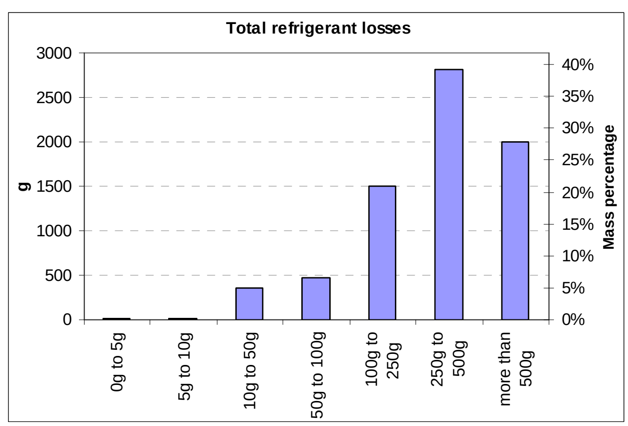


Figure 2.29 mass emission as a function of total refrigerant emissions (overall sample).

Refrigerant emissions that are less than 10 g (13% of cases) represent a total refrigerant release of less than 1% on a mass basis (see Figure 2.29). Large releases of refrigerant (more than 250 g per operation) represent 43% of the sample observed (45 vehicles and small can users), but it represents 78% on a mass basis.

Refrigerant mass repartition and ratios

Sample 1 (25 cases)

In Sample 1, the total mass of refrigerant contained in small cans before the charging operation is 14,395 g, corresponding to an average value of 575 grams per vehicle. The effective refrigerant mass charged in the vehicle is 8,557 g (342 g/vehicle) and represents 59% of the total initial mass. In contrast, the total refrigerant emissions due to servicing are 1,830 g (73 g/vehicle) representing 13% of the total initial mass. Moreover, the total can heel is 4,009 g (160 g/vehicle), which represents 28% of the total initial mass (see Figures 2.30 and 2.31).

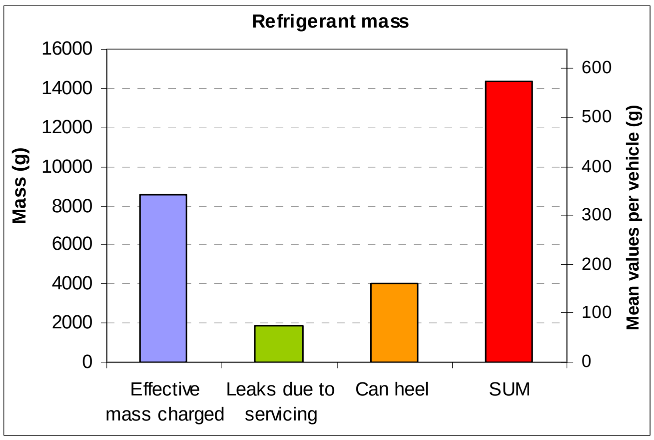


Figure 2.30 Refrigerant mass repartition (sample 1).

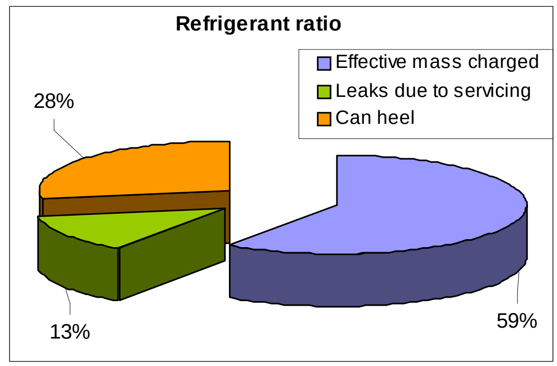


Figure 2.31 Refrigerant ratio (sample 1).

From the first sample, it could be concluded that DIYers who are not-familiar with small cans, lead to overall emissions of about 68% of what has been charged inside the MVACS.

Sample 2 (20 cases)

In contrast, when the DIYers are familiar with small cans, the overall emissions are about 21% of the effective mass charged.

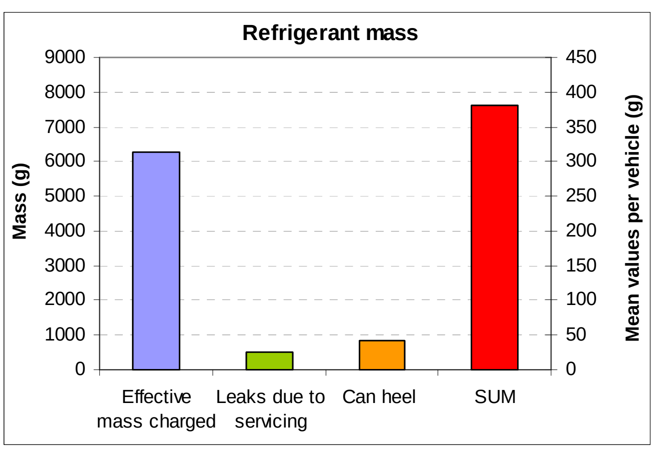


Figure 2.32 Refrigerant mass repartition (sample 2).

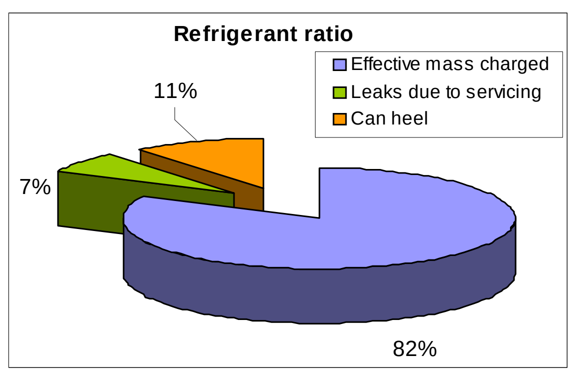


Figure 2.33 Refrigerant ratio (sample 2).

For sample 2, the total mass of refrigerant contained in small cans before the charging operation is 7,626 g, corresponding to an average value of 381 g/vehicle. The effective refrigerant mass charged in vehicles is 6,280 g (314 g/vehicle) and represent 82% of the total initial mass. In contrast, the total refrigerant emissions due to servicing are 512 g (25 g/vehicle) representing 7% of the total initial mass. Moreover, the total can heel is 834 g (41 g/vehicle), which represents 11% of the total initial mass (see Figures 2.32 and 2.33).

Overall sample (45 cases)

Considering the overall sample, that covers a wide range of randomly chosen people, the values obtained are in the middle between those obtained for Samples 1 and 2. Overall emissions are about 48% of the effective mass charged.

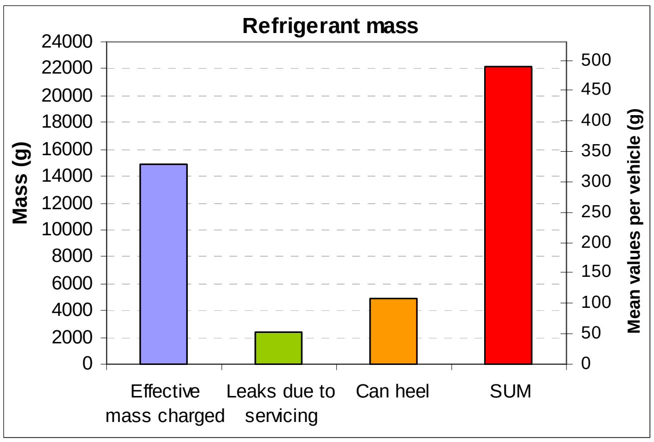


Figure 2.34 Refrigerant mass repartition (overall sample).

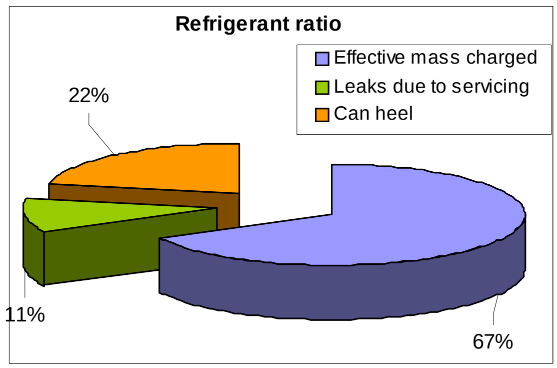


Figure 2.35 Refrigerant ratio (overall sample).

The total mass of refrigerant contained in small cans before the charging operation is 22,021 g, corresponding to an average value of 490 g/vehicle. The effective refrigerant mass charged in vehicles is 14,837 g (330 g/vehicle) and represents 67% of the total initial mass. In contrast, the total refrigerant emissions due to servicing are 2,341 g (52 g/vehicle) representing 11% of the total initial mass. Moreover, the total can heel is 4,842 g (108 g/vehicle), which represents 22% of the total initial mass (see Figures 2.34 and 2.35).

Values to remember

- 67% of initial mass contained in the cans are effectively charged into the system,
- 11% are directly emitted during the charging procedure,
- 22% remain in the can as heel. Sooner or later, they will be released to the atmosphere.

3. Analysis of current leak search and recharge by professional servicing in California

3.1 Introduction

The aim of this section is to analyze the refrigerant leak search as well as the recharging procedure done by professional servicing in California. In fact, a consumer unfamiliar with auto servicing, whose MAC system presents a partial or full failure, will mandate a professional in order to repair it.

A MAC failure on a CEP car has been simulated by having an empty or partially empty system. The overall professional procedure is described step by step from the preliminary AC check until the charge of the system. The operating mode of the service technician will be carefully described. After the charge, the CEP team recovers carefully the refrigerant in order to evaluate the accuracy of the recharge compared to the original system charge.

50 garages or AC repair centers have been considered in different areas in California in order to cover a wide range of cases. Garage visits and operations are detailed in Annex C.

3.2 Operating procedure to perform professional servicing analysis

3.2.1 Simulation of AC failure

A first proposal was to use rental cars to proceed and analyze the current professional servicing. Due to regulations, the CEP team was not allowed to use such vehicles nor operate on the AC system.

The first two operations were done using the CEP Cadillac Deville. The CEP team was obliged to use a different vehicle for the following reasons:

- as mentioned previously, the Cadillac AC system ran originally with R-12 refrigerant and had been retrofitted to R-134a
- two leaks were detected, the first one on the HP service valve, the other one on the compressor suction port
- after visiting two garages, the compressor clutch stopped operating.

Note: one professional declined to make any repair on this system (because of the retrofit from R-12 to R-134a); thus, when a professional declines, the only way for charging such a system is to use small cans.

For this reason, the CEP team had to buy a vehicle running on R-134a. All other visits (48 visits) at professional garages have been made using the CEP Mitsubishi Montero.

Two criteria motivated the choice of the Mitsubishi. The first and main criterion is the accessibility of the high and low-pressure servicing valves. The second one is the large cargo space available in the Mitsubishi Montero, which has been very useful to carry the CEP equipment.

In order to ask mechanics to repair the system, failure had to be simulated. The failure organized by the CEP team simulated real operating defaults of the MAC system. Two failures have been considered and are described below.

- The CEP team partially charged the MAC system with refrigerant. The mean refrigerant mass charged is around 100 grams. The MAC system did not present any leakage, rupture or malfunctioning. 43 cases were considered partially empty.

- The other 7 cases were similar to the first ones, but the system was emptied down to residual pressure equal to atmospheric pressure.

3.2.2 Description of the MACS used

The Mitsubishi Montero AC is a single-evaporator system using a thermal expansion valve with a parallel flow condenser and a fixed displacement compressor. The HP and LP service valves are easily reachable as shown in Photo 3.1.

The arrangement of AC components is also indicated on Photo 3.1. A scheme of the Montero AC system is shown in Figure 3.1.

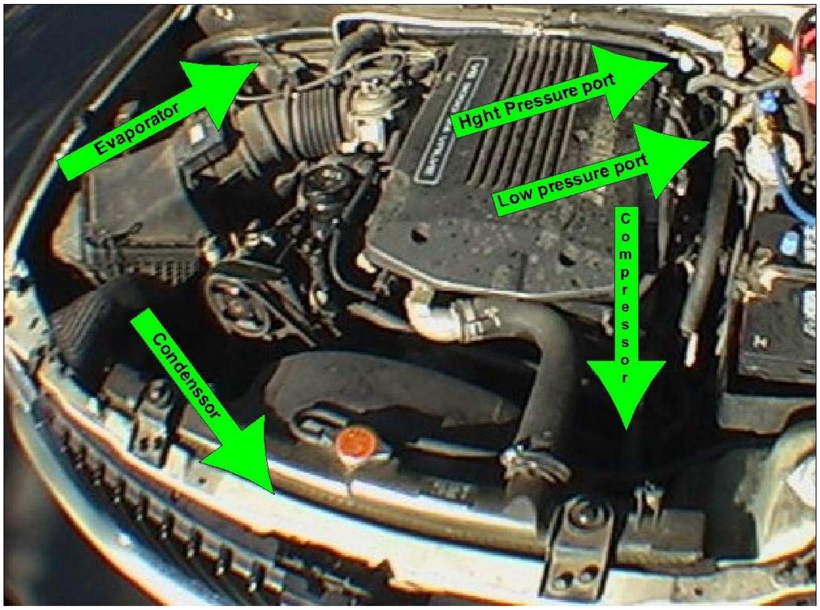


Photo 3.1 Under hood view showing the arrangement of the AC system components.

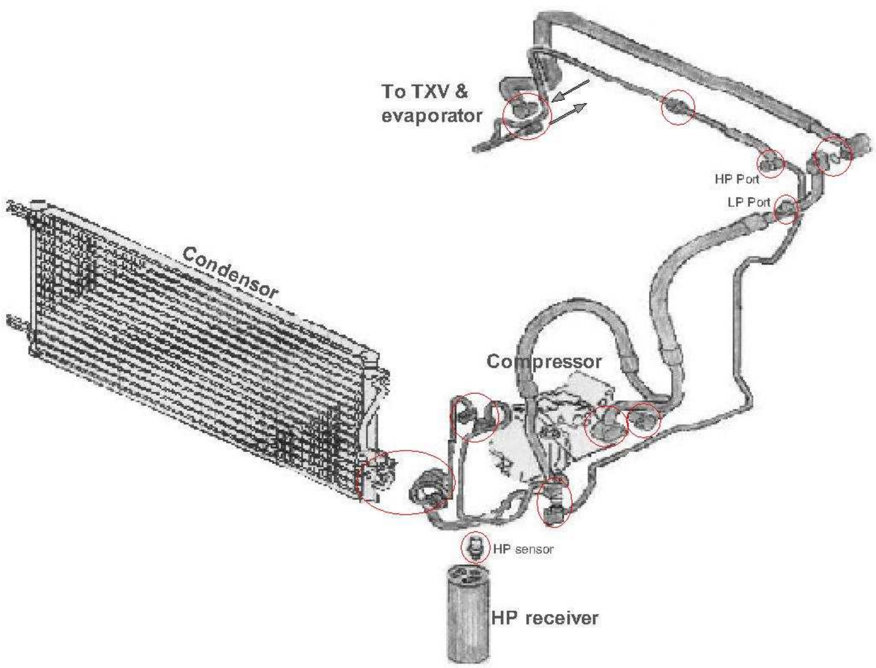


Figure 3.1 Schematic view of the Mitsubishi Montero AC system.

The potential leak sources on the Montero AC system are circled in red on Figure 3.1 and are as follows:

- The compressor rotating lip seal
- The compressor suction and discharge ports
- The inlet and outlet of the condenser, evaporator, and TxV
- The liquid receiver inlet and outlet
- The HP and LP service valves

- Fittings on the suction line and on the liquid line
- The high-pressure sensor
- The relief valve

Using an electronic detector, the CEP team performed a leak search on the MACS in order to check the system leak tightness. All parts and connections are verified. The whole system is tight except at the TxV where a very small leak is detected.

3.2.3 Selection of professional garages and sample description

50 garages have been visited in California. Garages are located in different areas in order to collect a wide sample, especially in Los Angeles and San Diego (see Figure 3.2).

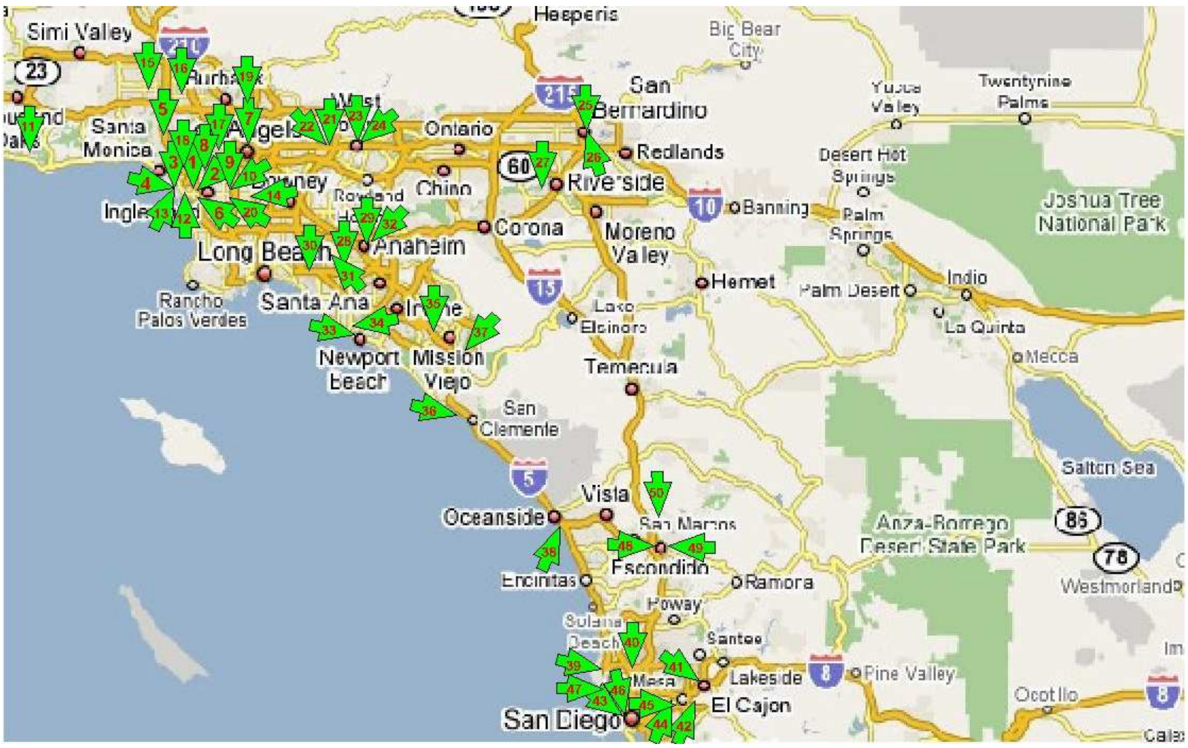


Figure 3.2 Location of garages visited in California.

Figure 3.3 shows the repartition of garages by size (technician number). 38 % of garages consist of 2 or 1 technicians. 46 % have 3 or 4 technicians. The remaining 16% have 5 technicians or more.

N: Number of technicians

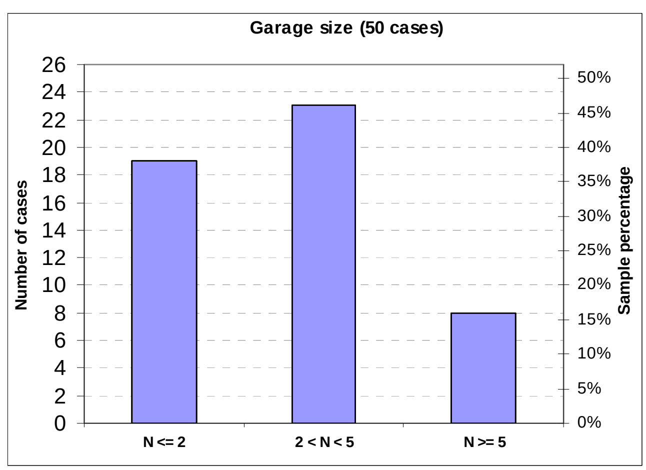


Figure 3.3 Garage sizes based on the number of technicians.

3.3 Analysis of current leak search and recharge by professional servicing

3.3.1 Preliminary AC check by professional servicing

The servicing technician usually makes a first AC check before completing any operation on the system. When the CEP team car is in the garage for servicing, the professional makes a preliminary AC check. The goal of this check is to make a first diagnosis on the failure cause. After this preliminary check, the servicing technician indicates a first diagnostic with a cost estimate. The client is subsequently free to accept or refuse the recommended actions.

This first check up could include:

- verification of the blown air temperature in the cabin,
- control of the compressor clutch,
- measurement of the low and high pressures (AC on),
- analysis of refrigerant using an electronic analyzer plugged on to the service valves,
- verification of the pressure inside the AC loop by pressing the HP or LP valves.

Figure 3.4 illustrates the actions made by the professionals before doing any operation on the system (actions done before giving any diagnosis).

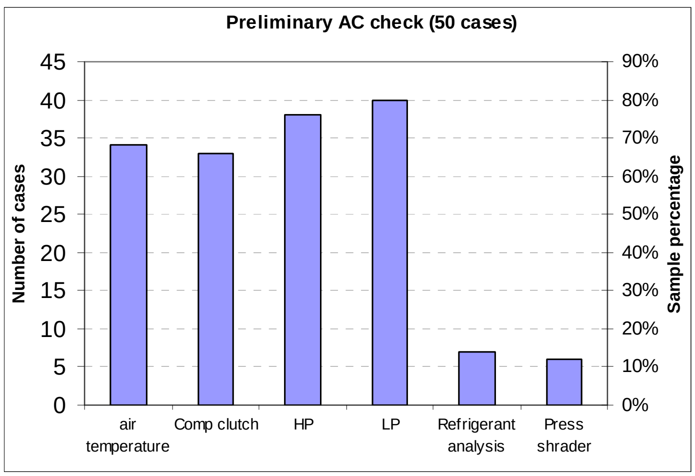


Figure 3.4 Preliminary AC check.

68% of professionals immediately check the blown air temperature in order to verify the availability of the fan and the coldness. two-thirds of the professionals directly verify the compressor clutch by visualizing or by hearing that it is ON.

80% verify the low pressure and 76% verify the high pressure inside the system using a manifold when the AC is running. The difference between the two pressures in running mode (HP and LP) is an indirect way to check that the clutch is ON. In contrast, when the engine and the AC are OFF, the pressure check indicates if any refrigerant remains.

Other actions have been noted: the analysis of the refrigerant (7 cases), and pressing the Schrader valve in order to verify that refrigerant is released (6 cases). It should be mentioned that the preliminary AC check could combine two or more verification types.

After doing these preliminary checks, professionals give a first diagnosis (see Figure 3.5). The primary action recommended was a recharge of the AC system (94% representing 47 cases). In

34 cases the advice given to the CEP team was to check the leak tightness (68%). It should be noted that in only 76 percent of these cases was the system checked for leaks.

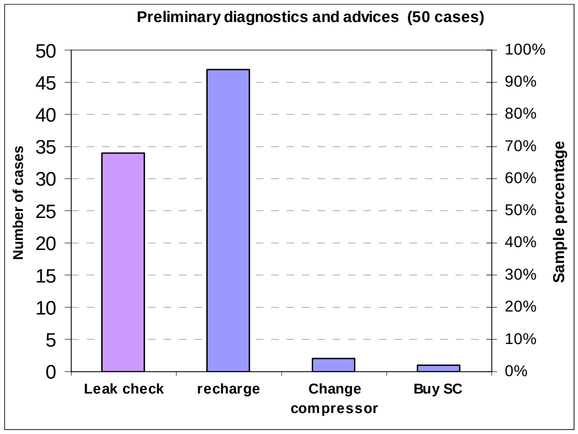


Figure 3.5 Preliminary diagnosis and recommendations.

Three particular cases should be mentioned: 2 garages recommended the CEP team change the compressor (note: these two recommendations were made for the Mitsubishi), the third one recommended buying small cans from an auto-parts store and recharge the AC.

3.3.2 Leak search and recharge by professional servicing

Depending on the diagnosis and the estimate given by the professional, the CEP team then has the choice to accept or decline the recommended actions.

When the professional is requested to operate on the vehicle, two evaluation steps are then performed. The first one is the leak search and the second one is related to the charging procedure.

Leak search procedure evaluation

Among the 50 technicians met only 47 have operated on the system. The three other cases are those who advised the CEP team to change the compressor or to buy SC from an auto-parts store.

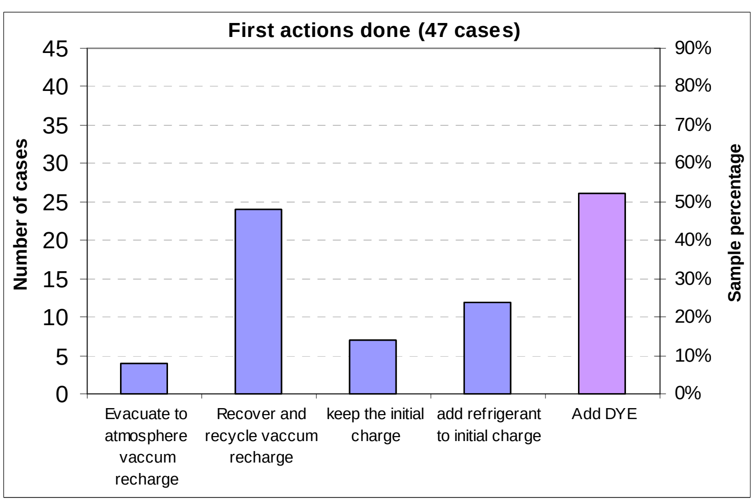


Figure 3.6 Small can users - Sample 1 description.

The CEP team noted that four types of main first actions are performed when the servicing is accepted. These actions are classified as follows (see Figure 3.6):

- The technician releases the refrigerant to the atmosphere, evacuates the system and recharges it (4 cases)
- The technician recovers the refrigerant, recycles it with an automatic machine, evacuates the system, and recharges it partially or completely (24 cases),
- The technician keeps the system untouched with the remaining charge (7 cases),
- The technician adds refrigerant to the remaining charge done by CEP (13 cases).

Whatever the method of operation, 26 technicians among the 47 have added dye to the system using the automatic group or a special charging kit. In addition to the fact that those 26 technicians have added dye, some of them did not perform the leak check. In fact, those technicians requested the CEP team to come back later for a leak search with a fluorescent detector (20 cases).

Even though 34 technicians have recommended verifying the leak tightness as a first diagnosis, only 26 have performed the leak check (see Figure 3.7). In all cases, 5 methods are indicated:

- Controlling the rise of the vacuum pressure (7)
- Direct UV detection (22) including 3 technicians who noticed that the system is already charged with dye
- Later UV detection (20)
- Electronic detection (14)
- Pressurized air or CO_2 with soap bubble (2).

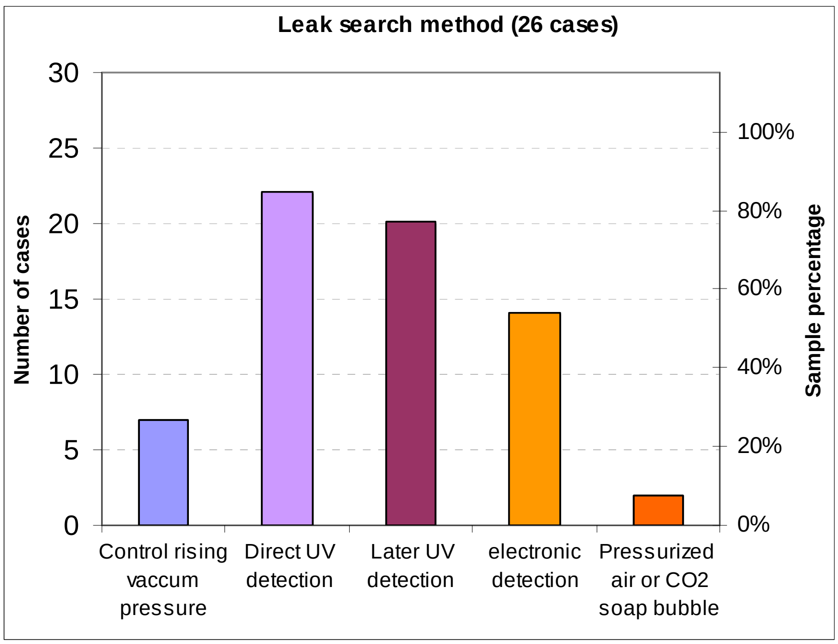


Figure 3.7 Leak search methods.

Note: Technicians who used soap bubbles to detect the leak are those who filled the system with pressurized air or CO_2. The technicians who used CO_2 proceeded later with a UV detection after releasing the CO_2 to the atmosphere, then charging with R-134a + DYE.

Several methods could be combined in order to verify the leak tightness of the system. When using an automatic charging machine, the pressure rise after evacuation is easily controlled (automatically). For UV detection, it is easier to add oil including dye. An electronic check could be also done later. The leak search time is directly related to the good will of the professional who does the servicing. If he spends more time searching leaks, the probability of forgetting potential leaks decreases.

Two technicians performed a careful leak search, spending the necessary time for that. 13 technicians have done it in less than 10 minutes. The 11 others took from 10 to 20 minutes (see Figure 3.8).

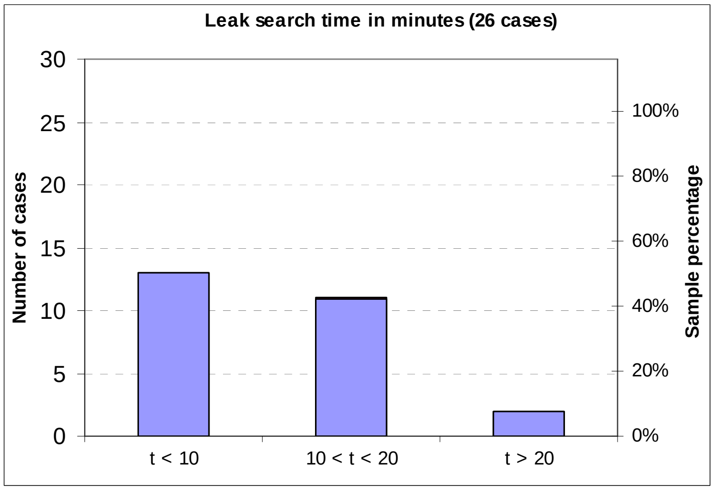


Figure 3.8 Leak searching time.

Among the 26 technicians who did the leak search, 8 of them found leaks (see Figure 3.9). But the leaks found do not correspond to those detected by the CEP team at the TxV connection. In fact, most of the cases were traces of UV at several sites:

- 4 leaks are detected at the service valves,
- 3 leaks are detected at the suction line,
- 1 leak on the condenser.

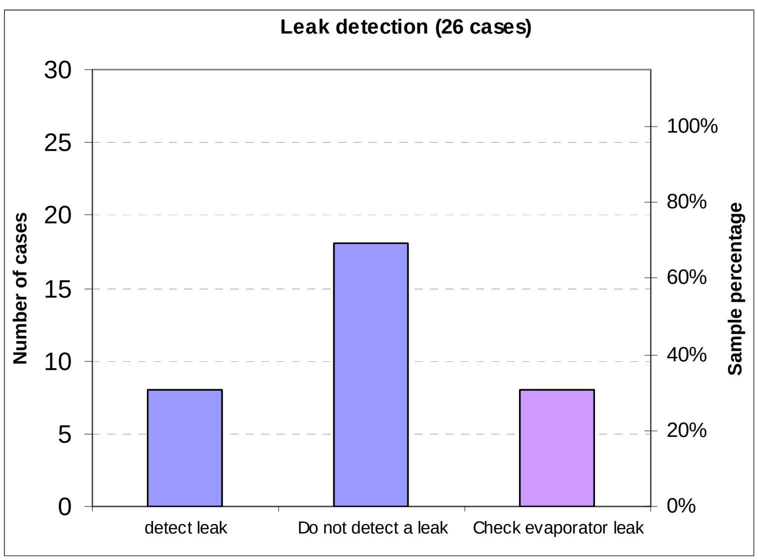


Figure 3.9 Leak detection.

Concerning the three technicians who found a leak on the suction line, one of them advised the CEP team to change the complete line, the second one to change the seal of the fitting, while the third one who found a leak on the suction port of the compressor, advised the team to change the line and the compressor. Of course, the CEP team declined doing that. The 20 other professionals did not detect any leak. None of the professionals detected the leak at the TxV.

It should be mentioned that 8 technicians verified the leak tightness of the evaporator by opening the evaporator box.

Recharge procedure evaluation

Among the 50 garages considered at the beginning, 40 have charged the system with refrigerant. The 10 others who did not charge the system made the following comments:

- 1 technician said that the system was overfilled with oil (garage number 4)
- 1 technician advised to buy a SC (garage number 7)
- 3 garages number 8, 11, 48 have given only advice
- 1 technician advised to buy a Schrader from an auto-part store (garage number 9)
- 2 technicians advised to change the compressor (garages number 22, 49)
- 2 technicians detected the leak at the suction line. The first recommended changing the line, the other one to change the suction seal (garages number 43, 40).

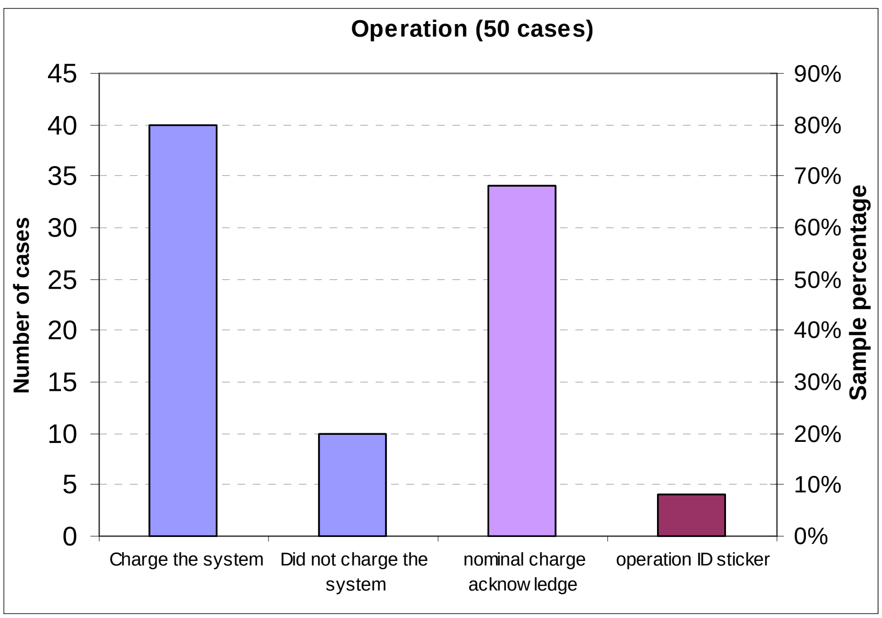


Figure 3.10 Recharge procedure.

Before charging the system with refrigerant, 34 technicians read the nominal charge indicated by the manufacturer under the hood. This information is crucial if the professional wants to exactly charge the system properly.

An important point has to be mentioned: only 4 professionals marked their operation by putting a sticker under the hood indicating the date of operation and the mass of refrigerant charged.

Three methods are used by professionals to charge the refrigerant in the system according to the equipment available in their garage.

- The use of an automatic machine successively doing the recovery and the recycling, the evacuation and the charge. 29 out of the 40 who did the recharge used automatic machines.
- The use of a refrigerant cylinder with a manifold and vacuum pump. 13 used this method but not all of them used the vacuum pump.
- The use of small cans to only charge the system, with neither recycling nor evacuation. In fact they only complete the charge (5).

Forty technicians performed the refrigerant charge (see Figure 3.11). Two of them made a complementary charge with small cans, the first using an automatic charging machine and the other using the cylinder and manifold. The first used the small can because he wanted to add a stop leak (4 oz), the other one added oil (SC 12 oz + oil).

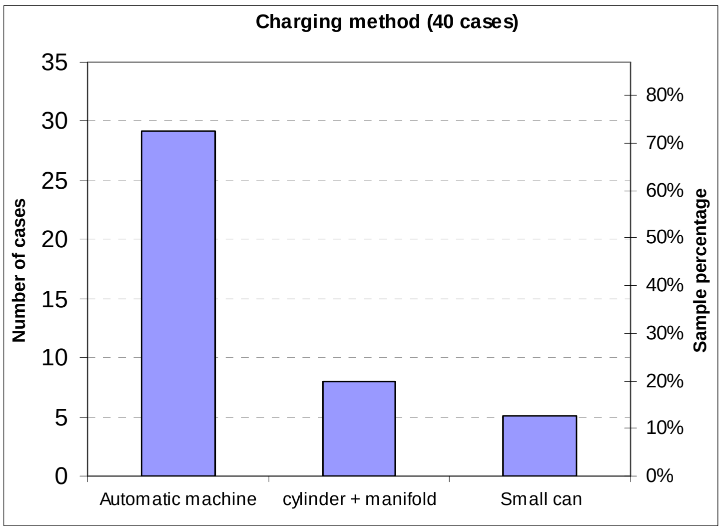


Figure 3.11 Charging methods.

Twentysix technicians added dye when charging the system. Twentyfour added oil to the system either by using an automatic machine or by injecting the oil directly with a specific charging kit. 1 technician charged with a small can including a “stop leak” additive.

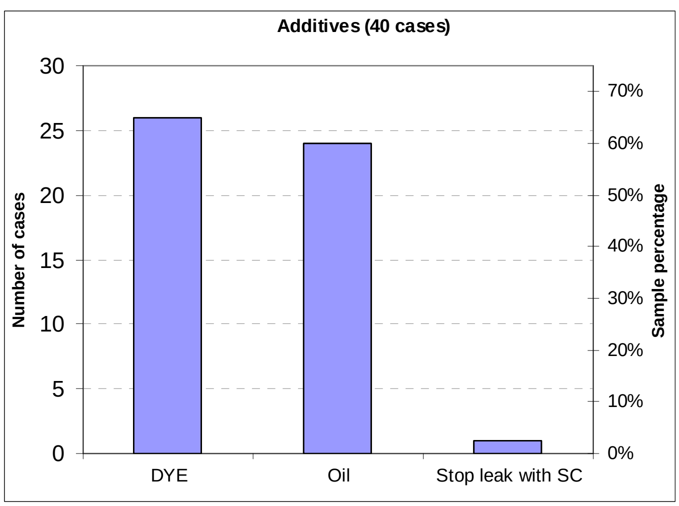


Figure 3.12 Additives.

In order to evaluate the refrigerant charges done by the professionals and compare it to the original charge indicated by the manufacturer the CEP team analyzed the precise recovery of refrigerant from the MAC system after each visit.

The technicians who charged are classified into four groups (see Figure 3.13).

- In blue those who charged with an automatic machine
- In green those who charged with a cylinder and a manifold.
- In orange those who charged with small cans
- In red those who combined two methods

Note: the red line indicates the manufacturer nominal charge of the vehicle (680 grams). The 2 peaks shown correspond to the 2 cases performed with the Cadillac.

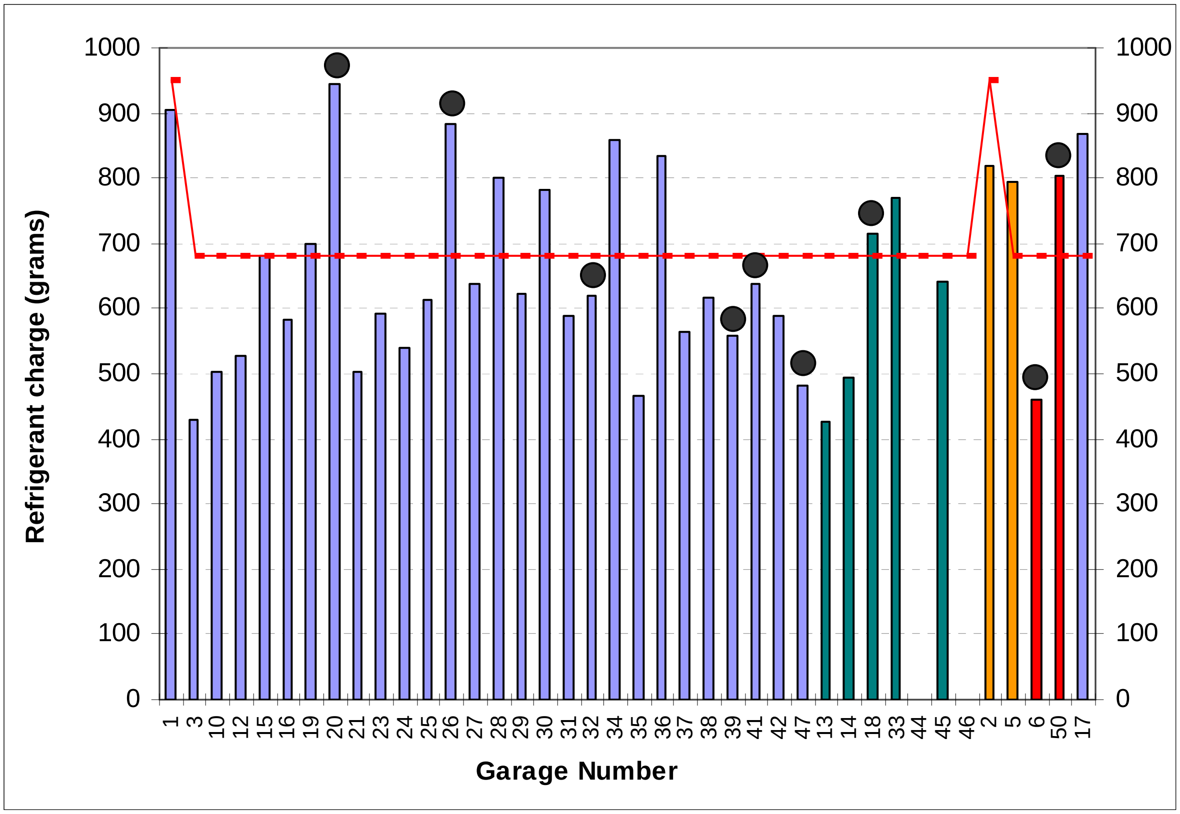


Figure 3.13 Refrigerant charge recovered for all professionals.

In Figure 3.13, the black dots represent those technicians that did not check the nominal refrigerant charge specified by the manufacturer. The first reason is the precision of the automatic machine. The second reason is that some professionals do not respect the manufacturer charge even if they read it before.

Those technicians who charged with a cylinder/manifold combination did not use a scale to weigh the refrigerant charge.

Garage number 44 released the charge to the atmosphere. Initially, the system was empty, so he charged the system without prior evacuation. The pressure increased when he ran the AC and the relief valve released the refrigerant. The same story occurred with garage number 46.

The summary of operations and actions during the 50 visits are presented in Figure 3.15.

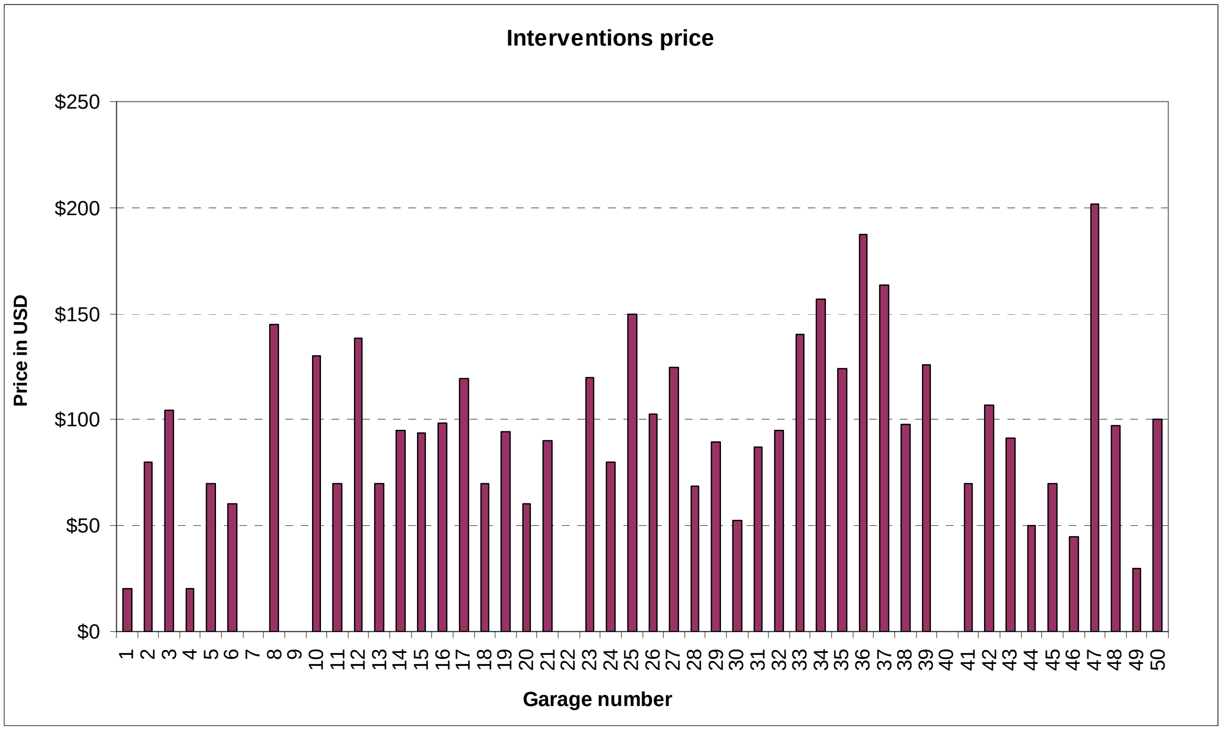


Figure 3.14 Prices as a function of garages and operation.

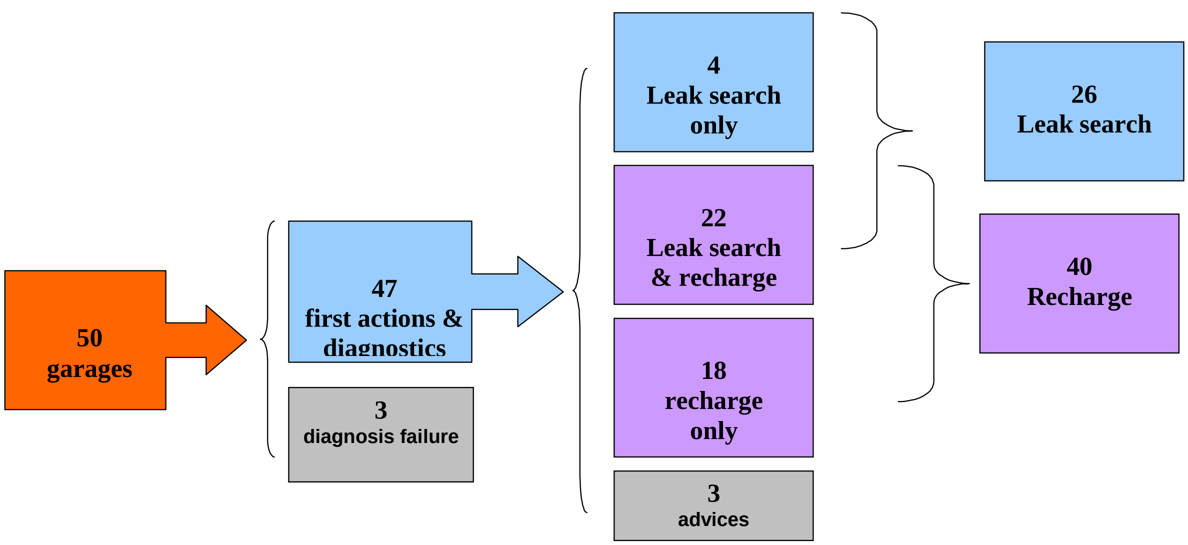


Figure 3.15 Operation summary.

4. Laboratory Testing

4.1 Evaluation of potential leak sources of professional servicing

The aim of this section of the study is to first evaluate the potential leak sources of refrigerant while a professional is intervening on the AC system. The second purpose is to recommend a series of actions to be done in order to ensure proper and less leaky maintenance.

4.1.1 System performances related to refrigerant charge

The cooling performance evolution of one of the 5 MAC systems studied in Section 1 is analyzed along a leaking process. A controlled slow leak is simulated when the MAC system is operating in a steady state regime. The tests are performed at the CEP laboratory using its MAC test bench (Photo 4.1).

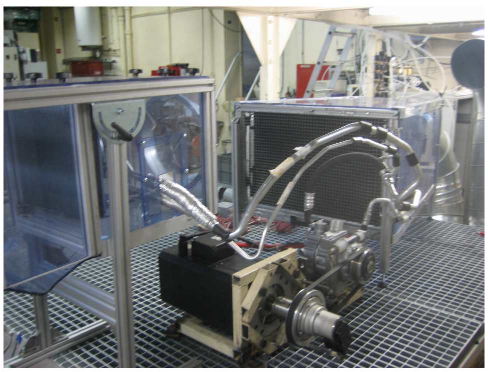


Photo 4.1 General view of the test bench.

Photo 4.2 Leak valve with micro counter.

The leak is controlled using a micro-counter precise valve (see Photo 4.2). The LFR is about 1.34 g/min. The leak is determined by weighting the recovered refrigerant in a cylinder connected to the low-pressure service valve.

The leak process begins when the steady state regime is reached: the leak valve is opened, the leak begins and continues until performance starts to decrease (very low cooling capacity, very high superheat, very low evaporating and condensing pressures). The leak test process takes place over 7 hours.

The system is charged at the beginning of the test with 700 grams of refrigerant. The mass of refrigerant, recovered 7 hours later, is 130 g.

The temperature is maintained at 30℃ at the evapor ator inlet. The air temperature equilibrium at the condenser inlet is 33℃. Tests are performe d at 1000-rpm compressor speed; the air mass flows on the condenser and evaporator are respectively 420 and 1540 m^3/h.

Figures 4.1 and 4.2 show respectively the condensing pressure and the sub-cooling evolutions as a function of the refrigerant charge.

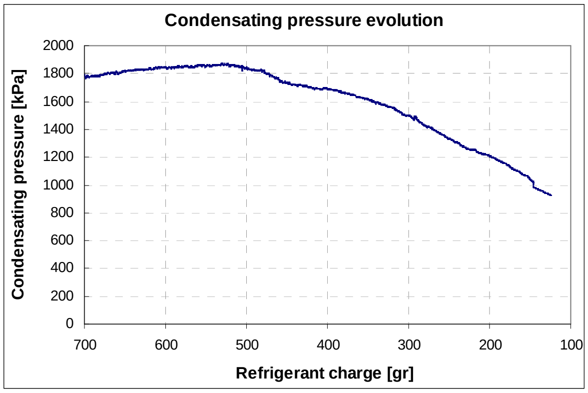


Figure 4.1 Condensing pressure evolutions.

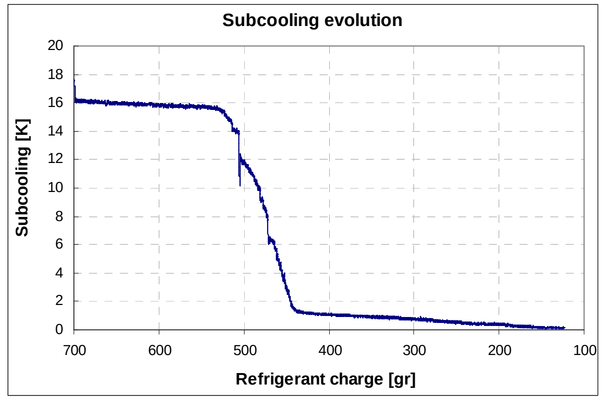


Figure 4.2 Sub-cooling evolutions.

Figures 4.3, 4.4 and 4.5 show respectively the evaporating pressure, the superheat, and the supply air temperature evolutions as a function of the refrigerant charge.

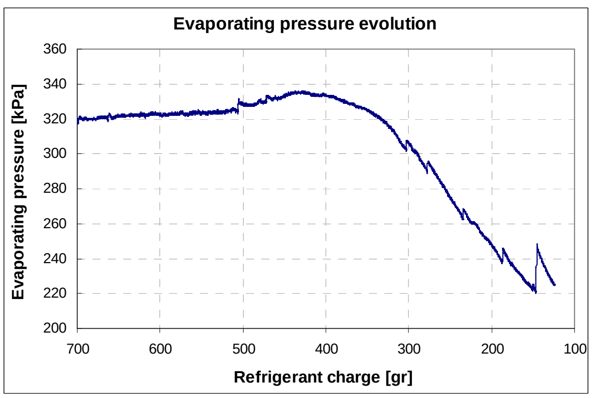


Figure 4.3 Evaporating pressure evolutions.

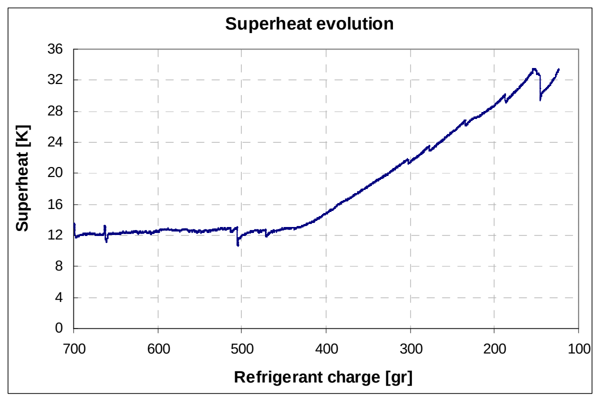


Figure 4.4 Superheat evolutions.

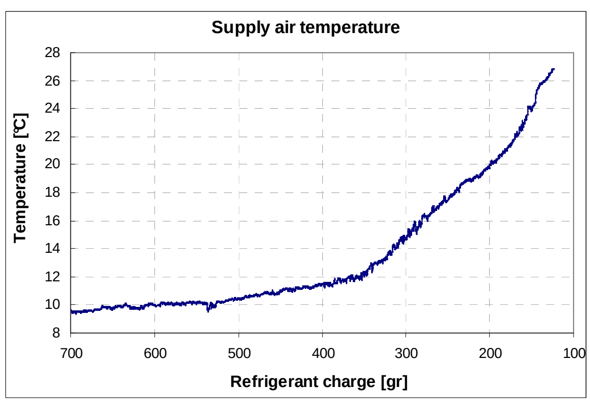


Figure 4.5 Blown air temperature evolutions at the evaporator outlet.

As seen in Figures 4.1 to 4.5 , three phases could be considered:

- The first phase corresponding to a system charge varying from 700 to 520 grams
- The second phase corresponding to a system charge varying from 520 to 340 grams
- The third phase corresponding to a system charge varying from 340 to 130 grams.

The first phase corresponds to the case where the liquid receiver still contains refrigerant in liquid phase whatever the remaining quantity. In this case, the system performance remains constant independent of the refrigerant quantity. All properties are unchanged, especially the cooling capacity.

The second phase corresponds to the case when there is no more liquid in the receiver, and that sub-cooling is fairly small. It has to be noticed that the sub-cooling decreases along the leaking process (see Figure 4.2), the superheat increases linearly (see Figure 4.4), and the air temperature at the evaporator outlet increases slightly (see Figure 4.5), meaning that the user or the mechanic cannot diagnose refrigerant loss under those temperature conditions.

The third phase is reached when the refrigerant charge is low. The heat exchangers are then oversized, and the condensing pressure decreases. The mass flow rate decreases at the TxV. The superheat and the air temperature at the evaporator outlet increase rapidly. The temperature level indicates the need for refrigerant recharge.

The system tested is equipped with a thermal expansion valve (TxV) and a fixed displacement compressor working in a steady state regime. For MAC system equipped with an orifice tube expansion valve (OT), the variations of pressures are more sensitive to the refrigerant charge, especially during the first phase.

Concerning the user, the only parameter to evaluate the system operation is the blown air temperature. According to Figure 4.5, no significant changes to the blown air temperature can be detected before losing about 50% of the refrigerant charge (340 grams).

4.1.2 Potential leak sources during a typical maintenance procedure

During a classic maintenance procedure performed by a technician, the potential emissions are related to:

- connection and disconnection of the recovery equipment to the service valve
- connection and disconnection of the charging cylinder or a small can
- rough verification of refrigerant charge by triggering the service valve
- direct evacuation of the MAC system without recovery
- emissions, when dismounting a component, if the recovery procedure has not been accomplished properly.

Significant emissions are due to direct evacuation and release of refrigerant from a small can, when not properly charged in the MAC system (the remaining quantity in the can, the “heel” is significant).

First operations done on the system before a leak search could be divided in four actions. According to Figure 3.15, the main action done is the use of automated recovery machine, which recovers, recycles, evacuates, and recharges (48% of the visited garages).

The second main action consists of adding refrigerant to the initial charge usually using cylinder and manifold or small cans (24%).

The third case is to keep the initial charge when searching the leak (14%).

The last case is the evacuation into the atmosphere in order to evacuate the refrigerant and recharge (8%).

Note: in the first case, all technicians have recovered the refrigerant before making a leak search, which is clearly wrong because the driving force of the leak is the refrigerant pressure inside the MAC system. .

Service valves

In fact, each time the service valves are used a leak occurs. The refrigerant quantity released is random and depends on the professional actions and equipment used. The leak is estimated usually in between 2 to 5g. Undue verification of refrigerant pressure by pushing the Schrader mechanism of the service valve may lead to emissions of up to 10 to 15 g.

When a professional connects the recovery equipment or cylinder using a quick coupler with moving rod, emissions are usually lower compared to connections fastened with a fixed rod. Photo 4.3 shows a quick coupler with a moving rod. When turning the valve, the rod moves to push the Schrader valve of the service valve. The leak tightness is assured before the Schrader is pushed down and to make the connection. In fact, these connections are connected first to the service valve and then the gates are screwed and opened.

In contrast, the quick couplers with a fixed rod open the gates at the moment they are connected. Photos 4.4, 4.5, and 4.6 show three types of quick coupler with fixed rod fastened with clips.

Photo 4.3 Quick coupler - Connection with moving rod by screwing fastened with clips.

Photo 4.4 Quick coupler - connections with fixed rod fastened with clips equipped with ball valve.

Photo 4.5 Quick coupler - connections with fixed rod fastened with clips.

Photo 4.6 Quick coupler - connections with fixed rod fastened with clips.

For couplers with a fixed rod, the tightness of the operation is random and dependent on the technician skills operating the system. If the Schrader valve is pushed straight, the valve will leak less or not leak at all. In contrast, if the Schrader is wrongly pushed, it will leak unexpectedly.

Clearly, the couplers with moving rods leak less. The coupler is first fixed on the service valve, the valve is then turned in a way to move down the rod and open the gate. The professional could check the way the valve is installed before opening the Schrader.

The charging method

The charging method is a potential source of refrigerant leak. As shown in Section 3.2.2, professionals can use three methods to charge a MAC system:

- with automated machines (72.5%)
- with cylinder + manifold (20%)
- with small cans (7.5%).

Usually, the automated machines perform the whole procedure without action by the professional (recovery, evacuation, leak test, and recharge). The machine is connected to the system via HP and LP service valves. The quick couplers used are usually with a moving rod, allowing good leak tightness. The connection between the machine and the system is set once.

Photo 4.7 Automated machine in service.

The major emission occurs at the connection valves (assuming that the machine is tight enough). Each time a hose is installed or removed, a small emission occurs. For this reason, the use of an automated machine leads to lower emissions because there are only 2 connecting actions on the HP and LP pressure service valves, and 2 disconnecting actions, which constitute the smallest number of connecting / disconnecting actions.

Another conventional method consists of using successively:

- a recovery machine,
- a recovery cylinder,
- a manifold,
- a vacuum pump.

So the possible number of connecting /disconnecting actions could be as high as ten, and thus refrigerant emissions are higher.

Photo 4.8 Recovery machine and cylinder.

Recovery efficiency and evacuation

Whatever the method used, the recovery machine allows recovering refrigerant at a specified limit (~4.3 psi absolute). The remaining refrigerant in the system cannot be recovered and so it is released to the atmosphere when using the vacuum pump.

The vacuum pump releases the refrigerant or air remaining in the system to the atmosphere. The remaining quantity of refrigerant depends on the recovery pressure limit, temperature, and the system internal volume. Typically, this quantity varies from 10 to 100 g depending on the fixed low-pressure threshold.

4.1.3 Recommended service procedure

In fact, a user goes to a garage for MAC servicing in two cases: the AC system is working poorly or not working at all. The reasons for such malfunctioning could be mechanical failure of the compressor or other components (evaporator blower, condenser fan, electronic command) or low refrigerant charge in the system. The professional should identify, by inspection, the source(s) of malfunctioning before connecting any hoses to the service valves.

As mentioned in the MACS (Mobile Air Conditioning Society) report on “recommended air conditioning inspection and preventive maintenance procedures”, the following steps have to be done leading to efficient and effective operation:

- Inspect the coldness of blowing air
- Inspect the compressor drive belt and clutch
- Inspect the flexible hoses and metal lines for signs of leakage or damage
- Inspect the compressor for signs of possible shaft seal leakage
- Inspect and clean the front of the condenser
- Check operation of all fans, blowers, air filters, and air circulation
- Check the functioning of the heater control valve (if any).

Once the mentioned actions are performed without any observations indicating the cause of failure, the professional can then operate on the system by measuring the pressure in order to confirm the presence of refrigerant.

1) AC OFF
When the AC is OFF, the pressure at the equilibrium phase is related to the ambient temperature and not to the refrigerant charge. In contrast, with a single-phase presence the pressure is related to both: refrigerant charge and ambient temperature. When the pressure is lower than the saturation at the corresponding ambient temperature, that means the system is filled only with the gas phase. To conclude, when the AC is OFF the system pressure indicates two cases:

- A partially empty system with gas phase (lower than saturation pressure or near atmospheric pressure).
- A partially or correctly filled systems if the pressure equals the saturation pressure.

So when the AC is OFF, the only conclusion that can be drawn from the value of internal pressure is associated with a nearly empty system (without any more liquid). It cannot indicate the quantity of refrigerant when any liquid phase is still in the system.

2) AC ON
The measurement of evaporation and condensing pressures indicates the functioning of the compressor. Moreover, it could be useful to estimate the refrigerant charge in the system by comparing the thermodynamic properties as shown in Figures 4.1 to 4.5.

Note: the only way to acknowledge the correct charge is to determine the sub-cooling: $Sb = T_{outlet\ condenser} - T_{sat}$ *(condensing pressure) requires not only pressure measurement but also precise temperature measurement at the condenser outlet.*

To conclude

- If the AC failure does not concern the refrigerant system (e.g. fan, air circulation, belt…etc), the professional should not operate on service valves
- The first action concerning the refrigerant should be leak search **before recovery**
- If the preliminary tests are carried out, the professional could then operate on the service valves in order to check pressures in standstill and in operation modes
- To recharge the system, the lowest emissions during servicing are obtained when using an automated machine with a quick coupler equipped with a moving rod
- The lower pressure threshold of the recovery machine pressostat has to be set as low as possible (typically 4.3 psi abs.); many are set just under atmospheric pressure (10 to 14 psi abs)
- For large leaks (> 40g/yr), the pressure raise after deep evacuation could be a correct method provided the oil is hot (T > 50℃) in order to avoid refrigerant outgasing from the oil
- The leak search using either dye and UV lamp or electronic hand leak detectors are both acceptable methods (see Section 4.3), but only the wrapping method allows for detection of partial leaks in the range of 5 to 15 g/yr
- In the presence of a leak, the fluid is recovered in order to repair the leak. In the absence of a leak, the fluid is recovered and refilled with the appropriate refrigerant charge.

4.2 Leak tightness tests of brand new and after use small cans

4.2.1 Introduction

The reference technique for DIYers to recharge a mobile air-conditioning (MAC) system is to connect a small can to the system. The small cans are filled with refrigerant, currently HFC-134a, but may contain lubricant, dye, and sealant. Both DIYers and professional technicians use these small cans.

Section 4.2 is dedicated to the laboratory measurements of refrigerant emissions from small cans before and after the first use.

The leak flow rate (LFR) is measured using an infrared spectrophotometer that continuously records the refrigerant concentration raise inside an accumulation volume where the can has been installed. The test method is identical to the one defined by the European Regulation 706/2007.

The leaks of 15 can samples have been measured before and after the first use, at three different temperatures making a total of 90 leak tests. Tests have been performed at the CEP laboratory. Tests show that refrigerant emissions depend strongly on the can and charging kit sealing technologies.

4.2.2 Description of small cans

A small can consists of a sealed casing that contains a pressurized refrigerant that will be transferred to a MAC system by means of a valve and a flexible hose, the charging kit. This can is usually built by assembling three different metallic parts: a jacket, a valve plate, and a bottom plate. The can leak tightness is achieved by placing an elastomer seal between the valve plate and the jacket, as well as a rolled edge seal on the bottom plate (see Photo 4.9).

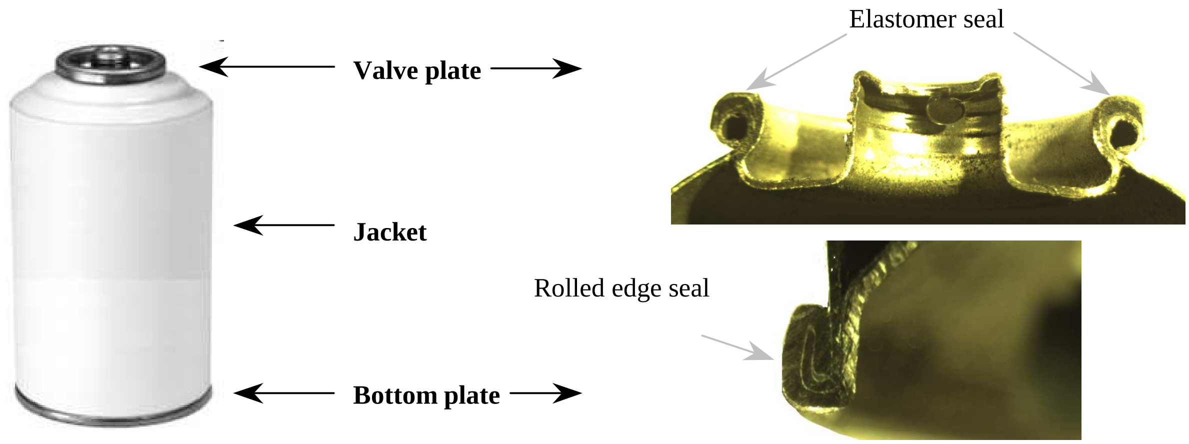


Photo 4.9 Small can main components.

The two families of small cans are defined by the valve technology:

- A self-closing valve inserted in the valve plate (type V, see Photo 4.10), or
- A valve, which is screwed and perforates the valve plate (type S&P, see Photo 4.12).

The charging kits also include a flexible hose connecting the small can to the air-conditioning system. The flexible hose and its low-pressure fitting are not considered in this leak test study since they are free of refrigerant before and after a partial use.

The **self-closing valve** cans are available in 14 oz and 19 oz capacities. The self-closing valve is installed in the valve plate (see Photo 4.10) and tightened with an elastomer seal (see Photo 4.11). An actuator pushes the stem downward (see Photo 4.11) and the refrigerant is released to the flexible hose. When the user stops acting, the stem closes and the container remains sealed.

Photo 4.10 Valve plate with a self-closing valve.

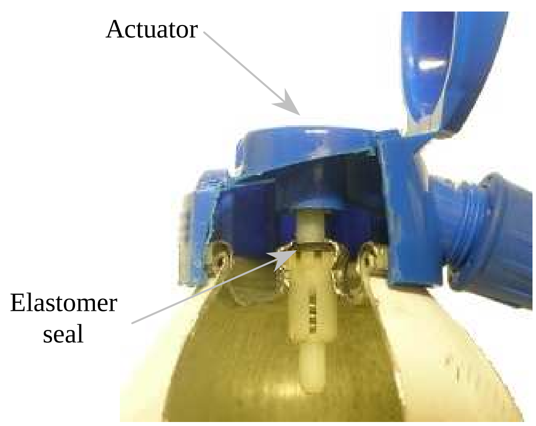


Photo 4.11 Sectional view of a self-closing valve actuator.

The **screwed and perforated** cans have a different valve plate that incorporates an externally threaded portion coupled with the valve plate (see Photo 4.12). This portion has a wall that will be penetrated by the pointer of a valve. The S&P cans are available in different capacities: 12, 13, 14, and 18 oz.

Two different valve technologies can be found in S&P cans:

- the shut-off valve, and
- the push button valve.

The **shut-off valve** is screwed on the can valve plate (see Photo 4.12). After that, the user turns the handle and the pointer moves downward and penetrates the valve plate wall releasing the refrigerant. To isolate the container, the user must continue turning the handle until the pointer reaches the maximum displacement and contacts the valve central body. Valve isolation is achieved by using an elastomer seal between the valve and the container valve plate, and a metal-to-metal contact between the pointer and the valve central body (see Photo 4.13).

Photo 4.12 Valve plate of an S&P can.

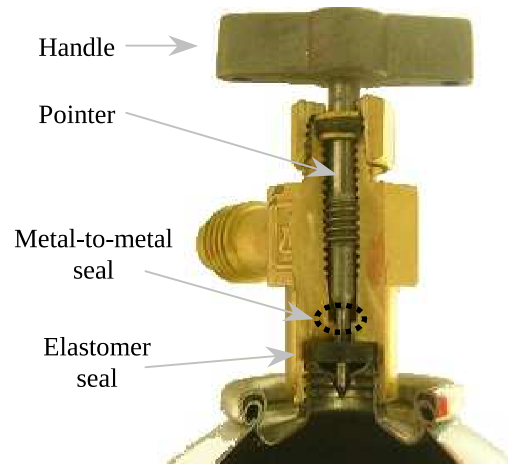


Photo 4.13 Sectional view of a shut-off valve.

The **push button valve** is also screwed on the can valve plate but has a different perforating mechanism from the shut-off valve. As the user screws the valve, a pointer penetrates the valve plate wall and the refrigerant automatically flows to the valve. The valve is tightened by four different seals (see Photo 4.15). When the handle is squeezed, the refrigerant is transferred to the flexible hose and once the handle is released, the valve and the container are isolated.

Photo 4.14 Rubber seal and pointer of a push button valve.

Photo 4.15 Sectional view of a push button valve.

The seal is the weakest link not only in the refrigerant container, but also in the charging kit. Seal performance depends on different variables, such as the surface topography, the seal material properties, the seal design, and the applied load. Accordingly, it is expected that, as the number of seals increase, the refrigerant emissions also increase.

Tables 4.1 and 4.2 list a large variety of small cans and charging kits available on the California market, their type, content, market price, and on-line net price. A list of small cans and their characteristics are presented in Annex A.

Table 4.1 Details of tested small cans.

Brand Name	Fitting type	Capacity (g)	Contents	CEP reference	Notes
Interdynamics	Valve equipped	510	R-134a + lubricant + leak sealer	C1-01	No rolled edge seal
Interdynamics	Valve equipped	510	R-134a + lubricant + leak sealer	C1-02	No rolled edge seal
Interdynamics	Valve equipped	396	R-134a + lubricant	C1-04	
Interdynamics	Valve equipped	397	R-134a + lubricant + leak sealer	C1-06	
Interdynamics	Valve equipped	398	R-134a + lubricant	C1-07	
Interdynamics	S&P	396	R-134a + lubricant + leak sealer	C1-03	
Interdynamics	S&P	396	R-134a + lubricant	C1-05	
Interdynamics	S&P	396	R-134a + lubricant + leak sealer	C1-08	
Interdynamics	S&P	398	R-134a + lubricant + leak sealer	C1-10	
Interdynamics	S&P	368	R-134a + lubricant + leak sealer	C1-13	
Technical Chemical Co	S&P	340	R-134a	C3-01	
Technical Chemical Co	S&P	340	R-134a	C3-02	
Technical Chemical Co	S&P	340	R-134a + leak sealer	C3-03	
EF Products	S&P	538	R-134a + lubricant + leak sealer	C4-01	
EF Products	S&P	538	R-134a + lubricant + leak sealer	C4-02	

Table 4.2 Details of tested charging kits.

CEP reference	Fitting type	Photo
F1-01	Valve equipped	
F1-02 F1-03 F1-04 F1-05	S&P S&P S&P S&P	
F1-07	S&P	
CEP reference	**Fitting type**	**Photo**
F1-09 F1-11 F1-12 F1-13	S&P S&P S&P S&P	
F4-02	S&P	

As indicated above, two series of tests have been performed on the two families of small cans: the first series on the brand new small cans, and the second series after a first use of the small cans.

The S&P cans are cheaper than those with valve or valves plus a pressure gauge. The S&P price varies according to the refrigerant content and the brand name. For this reason, people prefer to buy the charging kit once and then re-use it with S&P cans. It has to be noticed that the S&Ps are dominant (nearly 90% of the market, as assessed by several dealers) for two reasons: the more knowledgeable DIYers buy S&Ps due to the easiness of use; less knowledgeable, but price-oriented DIYers are also choosing S&Ps. Users prefer to buy S&P cans since they are cheaper than valve-equipped ones and they can re-use the charging kit with others S&P cans.

4.2.3 Tests and results

The aim of this section is to evaluate the can tightness, before and after partial use, in order to verify if the can is tight enough to keep the remaining refrigerant in the can for a later use.

The CEP has developed a method for determining the annual leak flow rate for MVAC components using infrared spectro-photometry [ACE05]. This method of testing is consistent with European regulation 706 / 2007 [EU706]. The leak flow rate of a can is measured in an accumulation volume (see Photo 4.16) by an infrared spectrophotometer. The raise of R-134a concentration is measured in the accumulation volume and translated into annual mass leak flow rate.

Photo 4.16 Accumulation volume where refrigerant annual leak is measured

Before leak tests, the infrared gas analyzer is calibrated using three different refrigerant concentrations: 0, 100, and 450 ppm. The cell volume is calculated using a calibrated leak (see Figure 4.6). The LFR measurement relative uncertainty is about 6%.

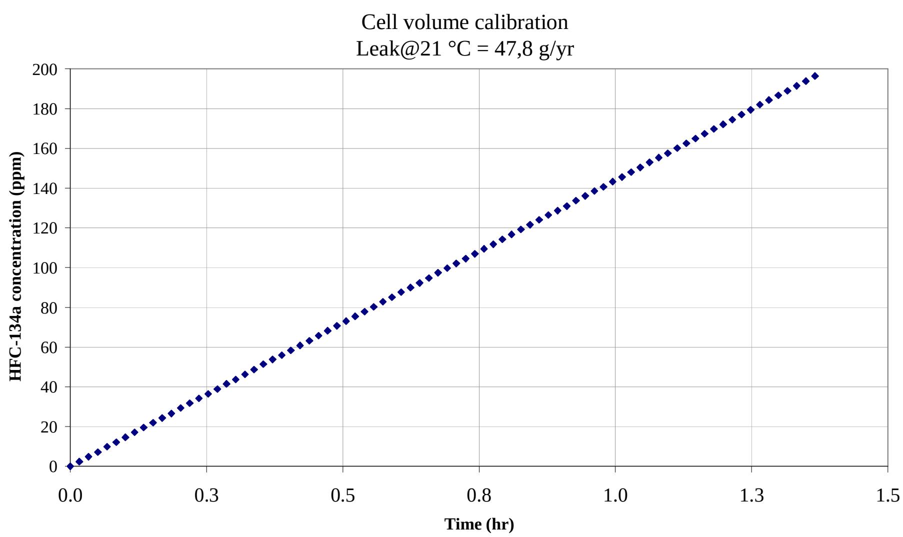


Figure 4.6 Refrigerant concentration raise using a calibrated leak.

As shown in Photo 4.16, the can is installed inside a hermetical volume where ambient pressure and temperature are controlled. Measurement starts when the preset temperature is reached. The annual leak flow rate is calculated using only the linear evolution of the refrigerant concentration.

The measurement accuracy is better then 0.1 g/yr.

As shown in Table 4.3, tests have been performed on S&Ps as well as on valve-equipped cans. The leak flow rates are determined before and after the use of cans. An S&P type can is considered new when the can tap of the charging kit is not screwed on it. A valve-equipped type can is considered new when it is intact as purchased.

Table 4.3 Small can leak test results.

Small Can				Leak Flow Rate [g/yr]						
Brand name	Net Weight [g]	Type	CEP Reference	new °C			used °C			
Interdynamics				30	35	40	30	35	40	Charging Kit
Ezchill	*510*	*V*	*C1-01*	*3.17*	*3.88*	*5.28*	*3.41*	*4.05*	*4.79*	*F1-01*
Ezchill	*396*	*S&P*	*C1-03*	*0.11*	*0.19*	*0.32*	*0.19*	*0.28*	*0.55*	*F1-02*
Ezchill	*510*	*V*	*C1-02*	*0.83*	*1.24*	*1.95*	*0.86*	*1.24*	*1.65*	*F1-01*
Ezcharge	*396*	*V*	*C1-04*	*0.62*	*1.03*	*1.73*	*0.55*	*0.86*	*1.51*	*F1-01*
Ezchill	*396*	*S&P*	*C1-05*	*0.37*	*0.60*	*1.05*	*441*	*526*	*714*	*F1-09*
Ezchill	*397*	*V*	*C1-06*	*0.97*	*1.59*	*2.27*	*0.70*	*2.08*	*3.34*	*F1-01*
Ezchill	*398*	*V*	*C1-07*	*0.66*	*1.09*	*1.64*	*0.75*	*1.14*	*1.84*	*F1-01*
Artic	*396*	*S&P*	*C1-08*	*0.39*	*0.62*	*0.97*	*1.52*	*2.23*	*2.60*	*F1-12*
Artic	*398*	*S&P*	*C1-10*	*0.41*	*0.62*	*1.09*	*3.09*	*4.48*	*5.86*	*F1-11*
High Mileage	*368*	*S&P*	*C1-13*	*0.33*	*0.49*	*0.77*	*0.41*	*0.62*	*1.06*	*F1-04*
Technical Chemial Co,										
Johnsen's	*340*	*S&P*	*C3-01*	*0.02*	*0.04*	*0.03*	*139*	*298*	*604*	*F1-13*
Johnsen's	*340*	*S&P*	*C3-02*	*0.004*	*0.005*	*0.01*	*37.0*	*50.1*	*67.8*	*F1-07*
Johnsen's	*340*	*S&P*	*C3-03*	*0.004*	*0.008*	*0.01*	*0.02*	*0.03*	*0.05*	*F1-05*
EF Products										
Sub-zero	*538*	*S&P*	*C4-01*	*0.04*	*0.05*	*0.08*	*0.04*	*0.05*	*0.08*	*F4-02*
Sub-zero	*538*	*S&P*	*C4-02*	*0.05*	*0.07*	*0.11*	*0.06*	*0.11*	*0.19*	*F1-03*

Leak tests on V-type small cans

For the valve-equipped cans (V-type), emissions are always slightly higher compared to S&Ps and in one case significantly higher (3.2 g/yr at 30℃). Values measured before and after can usage are of the same order of magnitude.

All cans are brand new and when the tests are made before use, the test is labeled Brand New (BN). Five of the V-type small cans have been tested. These cans are all manufactured by Interdynamics. Since the self-closing valve is installed on the can, the charging kit does not contribute to refrigerant emissions before and after a partial use.

Refrigerant emissions for new valve equipped cans are presented in Figure 4.7. As the leak flow rate and the saturation pressure are related in a quadratic relation, it is obvious that the leak flow rate increases with temperature. Refrigerant emissions from the *C1-01* can are three times higher than the other valve-equipped cans and lower than 6 g/yr.

The second series of tests performed after the first use of the five V-type small cans were labeled After Use (AU). As shown in Photo 4.13, the actuator only pushes the stem downward and, when released, a spring pushes the stem and closes the container. This means that changes on emissions after use could only be related to the rubber seal that moves with the stem. Figure 4.8 shows the variation of the leak flow rate after the first use is never higher than 1 g/yr and, for the *C1-01* can, it is 0.5 g/yr lower than a new can.

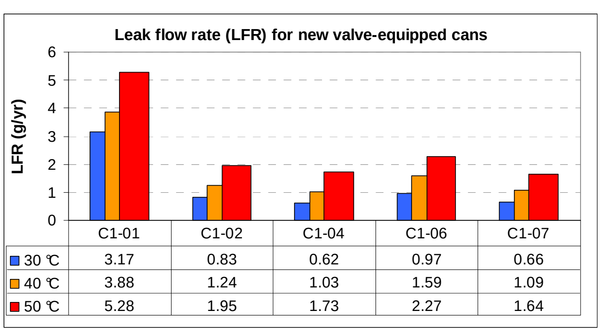


Figure 4.7 Leak test results of new V-type cans (BN).

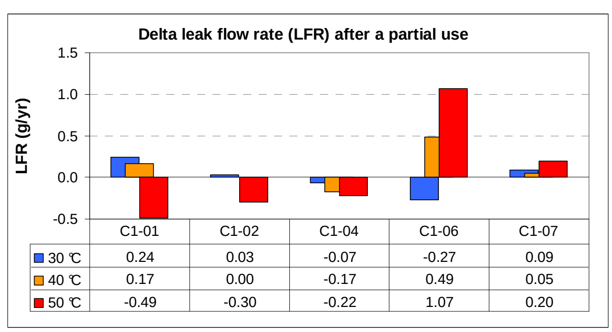
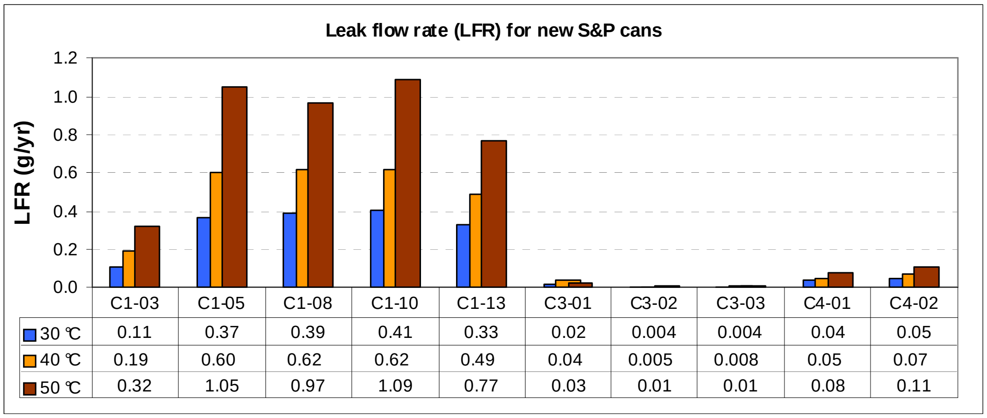


Figure 4.8 Leak test results of V-type cans (AU).

Leak tests on type S&P small cans

Five brand new S&P small cans have been tested. The leak test results for BN S&P small cans illustrates an important difference among the three different manufacturers that have been tested (see Figure 4.9). S&P small cans from manufacturer *C1*, are significantly more emissive than the *C4* and *C3* ones. For the same container pressure and type, we found refrigerant emissions from *C1* cans 100 times higher than that of the *C3* and *C4* ones.



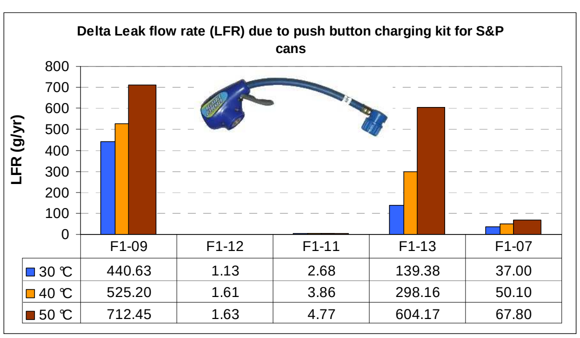
	C1-03	C1-05	C1-08	C1-10	C1-13	C3-01	C3-02	C3-03	C4-01	C4-02
30 ℃	0.11	0.37	0.39	0.41	0.33	0.02	0.004	0.004	0.04	0.05
40 ℃	0.19	0.60	0.62	0.62	0.49	0.04	0.005	0.008	0.05	0.07
50 ℃	0.32	1.05	0.97	1.09	0.77	0.03	0.01	0.01	0.08	0.11

Figure 4.9 Leak flow rate test results of S&P cans (BN).

These five S&P cans have been perforated for the first use and re-tested to evaluate the valve technology impact on the refrigerant emissions (see Table 4.2). These test results are presented in Figures 4.10 and 4.11.

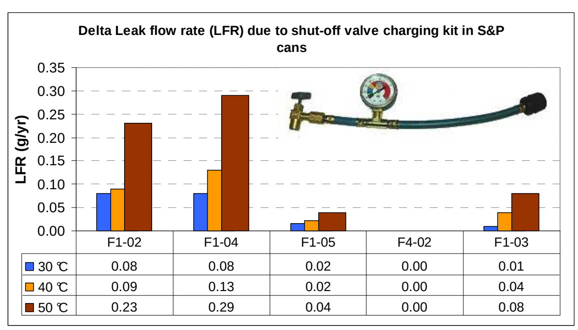
From the test results, it can be concluded that the push button charging kit technology is much more emissive than the shut-off valve. The lowest leak flow rate value obtained for the push button valve is about 1 g/yr and the highest one is about 700 g/yr, which proves the leak prone behavior of this technology.

The leak flow rates of S&P cans, after use, depend on the type of charging kit used. The leak flow rate of the F1-02 charging kit is quasi similar to the one of a new S&P can. In contrast, the F1-13 charging kit presents very high LFR (139 g/yr at 30℃) as well as F1-09, with annual LFR of 441 g/yr. F1-07 is neither satisfactory with 37 g/yr at 30℃. Of course, all charging kits where the refrigerant release is higher than 3 g/yr will quickly lead to an empty can.



	F1-09	F1-12	F1-11	F1-13	F1-07
30 ℃	440.63	1.13	2.68	139.38	37.00
40 ℃	525.20	1.61	3.86	298.16	50.10
50 ℃	712.45	1.63	4.77	604.17	67.80

Figure 4.10 Test result of the push button charging valve (AU).



	F1-02	F1-04	F1-05	F4-02	F1-03
30 ℃	0.08	0.08	0.02	0.00	0.01
40 ℃	0.09	0.13	0.02	0.00	0.04
50 ℃	0.23	0.29	0.04	0.00	0.08

Figure 4.11 Test result of the shut-off charging valve (AU).

It can be concluded that some charging kits cannot be used on S&P cans after a partial charge, leading to a complete loss of the remaining refrigerant. Moreover, when using F1-13 charging kits during operation the CEP technician noticed significant emissions.

When using the charging kit *F1-09* at 30℃, the annual leak flow rate exceeds 400 g/yr , meaning that the refrigerant container will be empty in a few days. If a user chooses to use a shut-off valve and close it after the re-charging process, the increase in refrigerant losses could be neglected.

The shut-off valve technology slightly impacts refrigerant emissions and, for the charging kit *F4-02*, has no impact at all. The high performance of the shut-off valve is related not only to the use of just two seals, but also to the applied load in both seals. One of them is metal-to-metal (see Photo 4.12).

4.2.4 Conclusions

Based on the 90 leak tests presented above, refrigerant emissions from small cans before and after a partial use could be significant and depend strongly on the container and charging kit technology.

Two different small can technologies have been tested: the V-type and the S&P type. As expected, S&P small cans before use show lower emissions compared to V-type small cans. Particularly, the S&P coming from the brand name *C3* shows the lowest emission level, which is nearly nil (see Figures 4.7 and 4.9). This means that, when stored in the sales store, the S&P type small cans leak less than the V-type ones.

The charging kits are adapted to the container type. For valve-equipped cans, the charging kit does not modify refrigerant emissions. Therefore, they present almost the same emission level after a partial use (see Figure 4.8).

Two different charging valves have been tested for S&P type cans. The push button type has highly irregular emission behavior and an increase of 712 g/yr has been measured at 50℃ (see Figure 4.10). The shut-off valve has been tested in the same conditions and presents emissions lower than 0.3 g/yr (see Figure 4.11). It has to be noticed that the S&P cans with a push-button charging kit and the valve-equipped cans have a self-closing system that prevents the user from emptying the container in a few seconds.

In order to reduce refrigerant emissions before and after the re-charging process, appropriate cans and charging kits have to be chosen. These test results suggest the use of S&P cans with a shut-off valve charging kit will minimize HFC-134a emissions.

4.3 Sensitivity of Different Leak Search Methods

4.3.1 Introduction

In order to determine the effectiveness of the leak search methods, a comparative study of leak sensitivity to: dye, electronic leak detectors, and the soap bubble method was carried out, using the infrared spectroscope to measure exactly the LFR that can be detected by each method.

Five fittings with the same design and different LFRs have been chosen (see Photo 4.17). They are composed of two flanges and one o-ring seal, and put together with a screw.

Photo 4.17 Fittings technology used for this comparative study.

4.3.2 Test procedure

First, each fitting has been put under pressure with HFC-134a and installed inside an accumulation volume to be leak tested using an infrared spectrophotometer (IS). Refrigerant pressure is set to 770 kPa and the fitting temperature to 35℃, superheated to 5℃ to avoid refrigerant condensation inside the component. This leak test is the same as the one described for the small can leak tests. This first test is followed by a leak search using an Electronic Leak Detector (ELD) and a Soap Bubbles (SB) test.

The ELD leak detection is achieved by placing the sniffer as close as possible of the component and then moving slowly all around the flanges junction. If the leak detector audible alarm intensifies, then the leak is considered as detected. Before the leak search, the ELD is checked with a calibrated leak of 6 g/yr (see Photo 4.18).

Photo 4.18 Calibrated leak for checking the ELD.

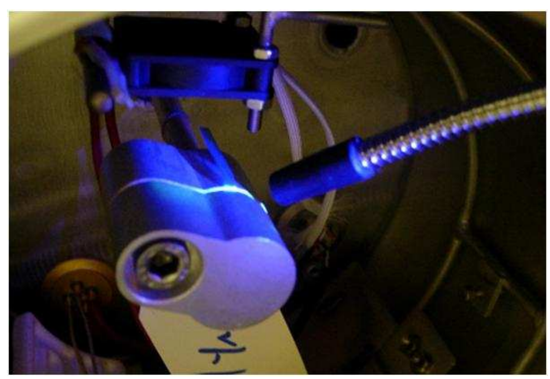


Photo 4.19 Leak detection with Electronic Leak Detector.

The SB leak detection is achieved by spraying the flanges junction with a soap solution. If the formation of bubbles is visible to the naked eye, then the leak is considered detected.

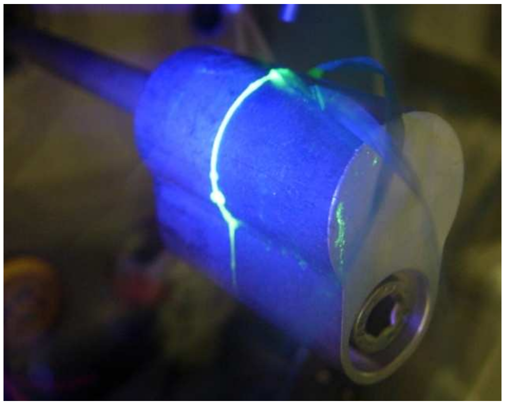


Photo 4.20 Leak detection with DYE

Photo 4.21 Leak detection with Soap Bubble (1200 g/yr).

The refrigerant LFR measured for Samples 4 to 6 have been performed before the dye visualization.

Second, without disassembling the flanges, fittings have been charged with refrigerant HFC-134a, PAG lubricating oil, and dye. The refrigerant pressure is set to 770 kPa and the fitting temperature to 35℃. Then, they have been observed with a fluorescent light to determine the time taken by the refrigerant, oil, and dye to go through the leaky seal (see Photo 4.19). Once the test has led to positive detection, the refrigerant LFR is measured with the infrared spectrophotometer. Third, the ELD and the SB techniques are also tested (see Photos 4.20 and 4.21).

4.3.3 Leak test results and conclusions

When comparing Tables 4.4 and 4.5, the fittings being in the same conditions, the lubrication effect is very significant especially for high LFRs. For example, for fitting no. 1, the lubrication of the fitting results in reducing the LFR from 662,000 g/yr to 14.7 g/yr, and for Sample no. 2 from 1,490 to 120. This effect is systematic even if no general law can be derived from those tests. Lubrication of all fittings leads to significant improvement of leak tightness.

For dry contact, only ELD and SB can be used because dye is diluted in the oil. As it can be seen in Table 4.4, the practical limit of detection has been 7.2 g/yr for both ELD and SB.

Table 4.4 LFRs of fittings with dry contact.

1st leak test - Dry contact			
Test method / Sample	IS [g/yr]	ELD	SB
No.1	662,000	Detected	Detected
No.2	1,490	Detected	Detected
No.3	515	Detected	Detected
No.6	300	Detected	Detected
No.4	7.2	Not detected	Not detected
No.5	0.28	Not detected	Not detected

For the second series of tests with lubricated joints, strangely enough the threshold detection has been different and even a LFR of 14.7 g/yr has not been detected either by ELD or SB but has been detected by dye.

When comparing Samples 1, 2, and 3, it can be deduced that the lower the LFR, the longer the time the dye has to go through the leaky fitting. Sample 3 seems to indicate that a leak as low as 5.7 g/yr can be detected by dye only after 11 hours, this leak was not detected either by ELB or SB.

Table 4.5 LFRs of fittings with lubricated contact.

2nd leak test - Lubricated contact				
Test method / Sample	IS [g/yr]	ELD	SB	DYE [hr]
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	*

*No evidence of DYE after 21 days of test

** Very small bubbles

***No evidence of DYE after 15 days of test

After a 21-day test, no evidence of dye has been noticed for Samples 4 and 5.

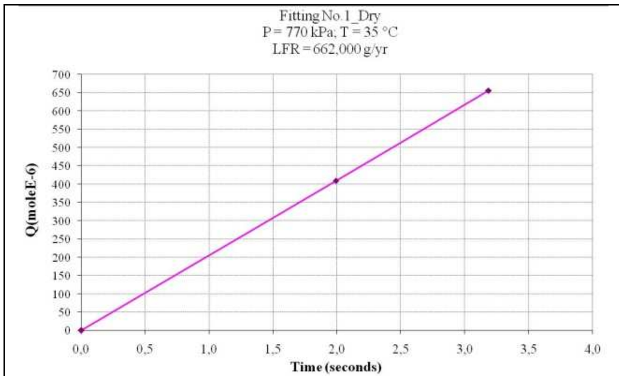
For Sample 2 (14.7 g/yr with a lubricated contact), the SB method has generated very small bubbles, which are very difficult to visualize.

It has to be noticed that in ELD and SB leak test methods, the leak search strongly depends on the leaky component accessibility. If fittings are not fully accessible, the leak visualization or location can be very hard to find. For the compressor shaft seal, the refrigerating system most leaky seal, detection using ELD and SB methods is impossible because the clutch assembly hides the shaft seal.

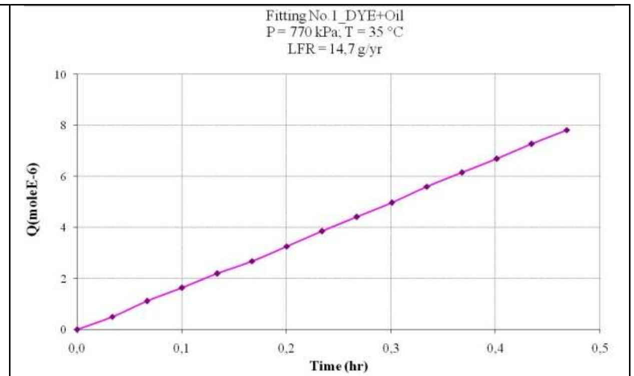
In conclusion, adding dye to the oil seems to be a simple and efficient way to detect leaks in the very busy environment under the vehicle hood. Those first tests do not indicate a significant advantage of usual methods (ELD or SB) compared to the use of dye.

The detailed fitting emissions are presented in Appendix A.

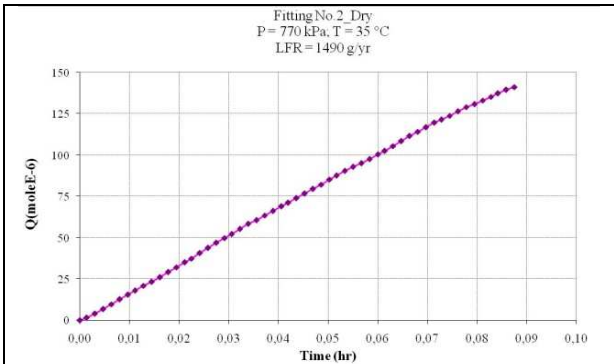
Appendix A: detailed fitting emissions



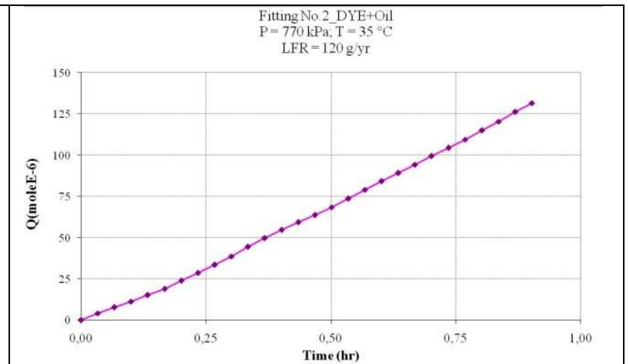
Fitting No.1 : Dry contact



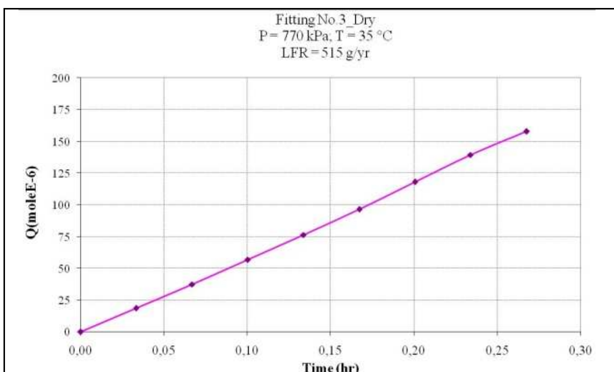
Fitting No.1 : Lubricated contact



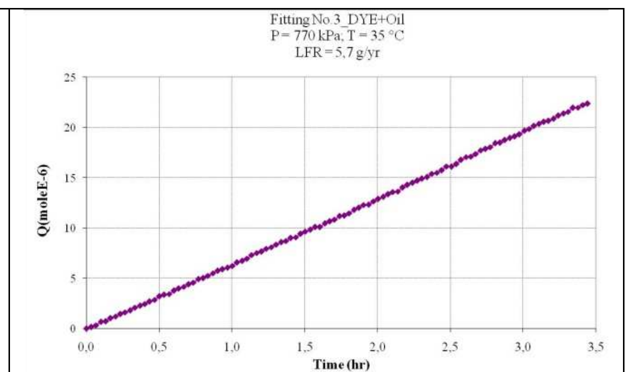
Fitting No.2 : Dry contact



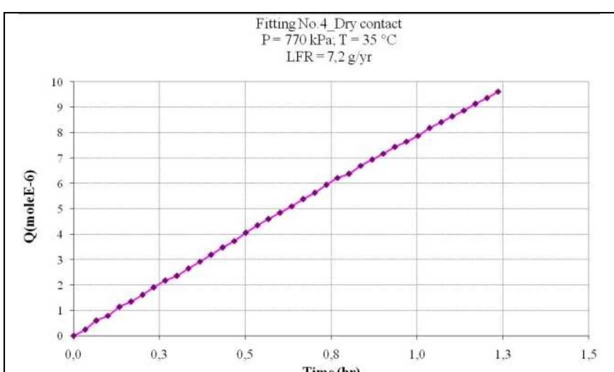
Fitting No.2 : Lubricated contact



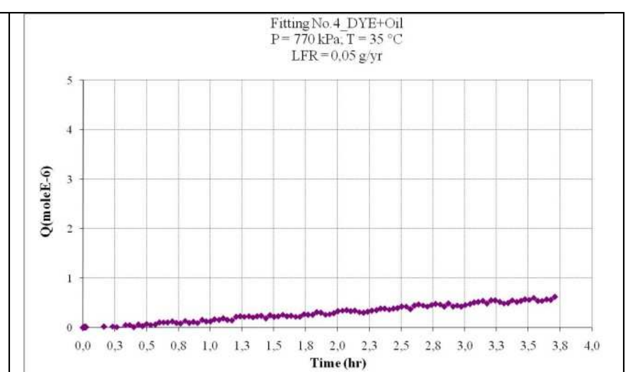
Fitting No.3 : Dry contact



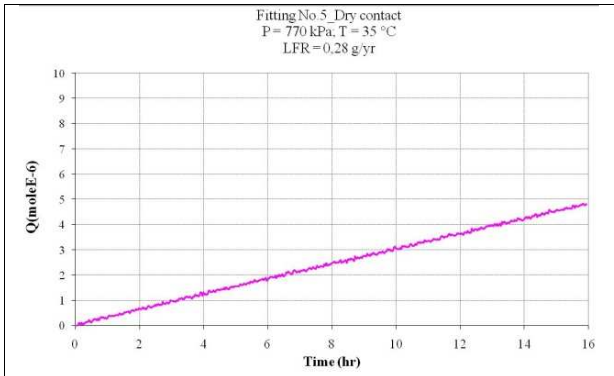
Fitting No.3 : Lubricated contact



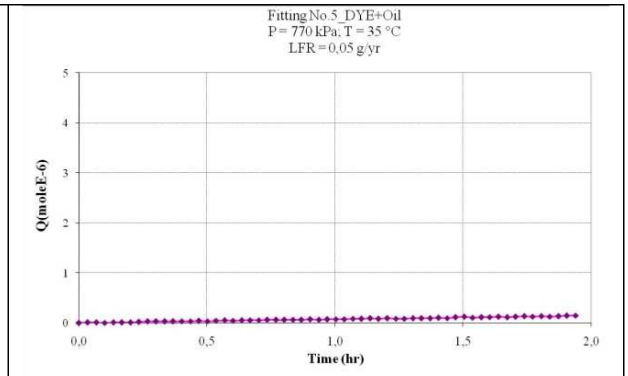
Fitting No.4 : Dry contact



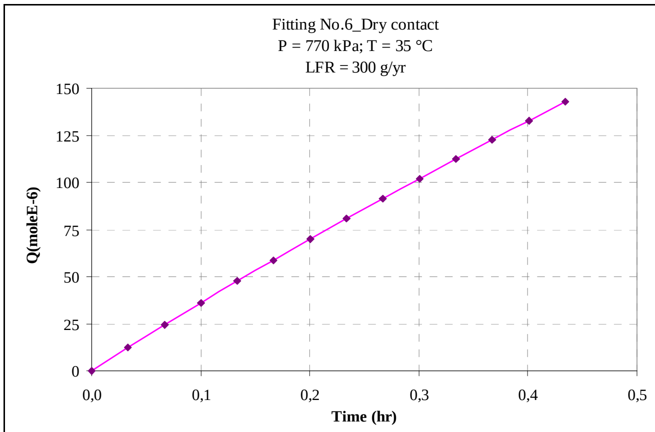
Fitting No.4 : Lubricated contact



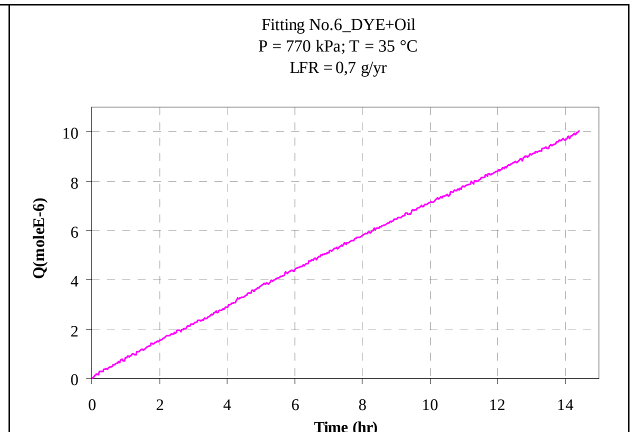
Fitting No.5 : Dry contact



Fitting No.5 : Lubricated contact



Fitting No.6 : Dry contact



Fitting No.6 : Lubricated contact

5. Evaluation of the sales of HFC-134a disposable cans in California

Two sources are available to evaluate the number of small cans sold in California. Based on the 2006 CARB consumer project survey, the number of HFC-134a small cans sold in California is close to 2 million cans per year equivalent to 0.85 MMT CO_2 equivalent per year. This data has been presented by CARB at the Scottsdale SAE Conference 2008 [ZHA08].

In 2005, E. Hoffpauir of MACS presented the refrigerant sales of HFC-134a for servicing and for new vehicles, as shown in Figure 5.1. So if California represents 10% of the U.S. small can sales (which is a typical assumption), the equivalent CO_2 is higher, in the range of 1.3 MMT CO_2 equivalent. In any case, the order of magnitude of direct emissions is in the range of 0.33 MMT CO_2 equivalent per year due to emissions during servicing by DIYers.

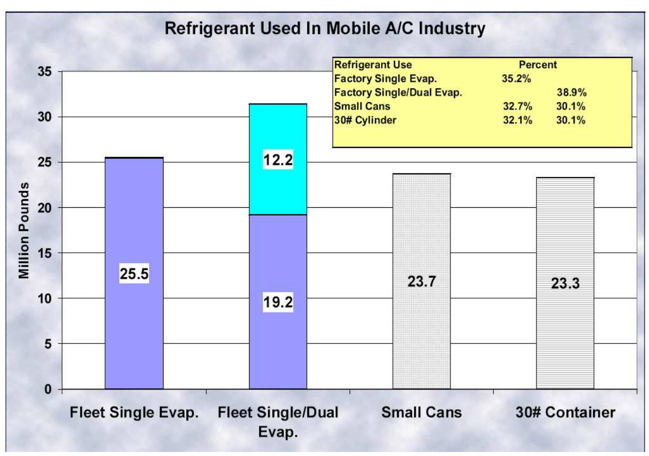


Figure 5.1 HFC refrigerant sales for MAC systems - 2003 [HOF05].

6. Summary, conclusions, and recommendations

The primary purpose of this project was to provide data for the regulatory development of a discrete early action under AB 32, the California Global Warming Solutions Act of 2006. The purpose of the regulatory measure was to reduce the emissions of high-GWP refrigerants during the re-charging of MVACs by DIY individuals. CEP staff also performed a field study of MVAC servicing by professional technicians in order to evaluate the procedures followed in professional servicing and repair. Additional data was generated which may be helpful in the development of other proposed regulations concerned with the emission reduction of high-GWP refrigerants from MVAC systems.

The CEP staff performed two field studies including measurements of refrigerant emissions from the DIY re-charging of MVAC systems in the field. The first field study focused on analyzing approximately 50 Do-It-Yourself (DIY) recharges on auto A/C units using from one or more small containers of automotive refrigerant. Through the measurements of refrigerant masses in the MVAC system and the container, the CEP staff calculated refrigerant emissions and their components during the DIY re-charging procedure. The second field study was a qualitative study of the diagnostic and servicing practices of professional A/C servicing facilities when an MVAC system is significantly undercharged.

In addition, laboratory tests were conducted to demonstrate: (1) how much refrigerant would be lost before the cooling performance of a selected MVAC began to deteriorate significantly, (2) a comparison of the sensitivity of different methods of leak detection, (3) the typical leak flow rates from "small cans" and their charging apparatus, and (4) the typical leak flow rate of the MVAC systems in the five most popular cars in California.

Refrigerant Emissions from DIY MVAC Re-Charging

Based on the field testing with DIY volunteers, two-thirds of the "small container" refrigerant is charged into the MAC system while 1/3 is emitted to the atmosphere. See the figure on the right. Almost 80 percent of the volunteers chose the S&P type cans because they already have the charging assembly and it is cheaper. It is also important to note that a small number of DIYers was responsible for the majority of the emissions. 43 percent of the operations resulted in 78 percent of the emissions indicating the need for proper training.

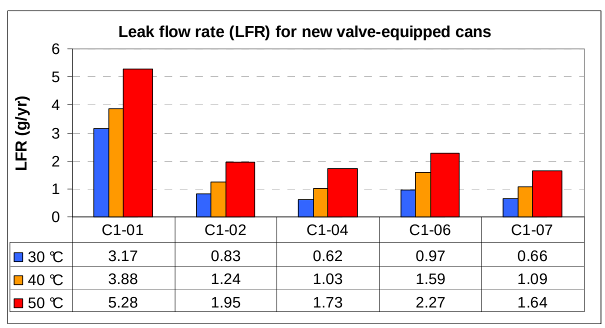


Figure a – Components of a DIY Refrigerant Charge.

The main drawbacks associated with non-professional servicing are:
(1) DIYers not knowing the amount of refrigerant remaining in the system or the manufacturers' specified charge, (2) MVAC system leak search and repair are not conducted, (3) DIYers not recovering the refrigerant from the MVAC system prior to re-charging, and (4) incorrect instructions on the container labels.

***Recommendations*:** For the DIY practice to be effective the use of the pressure gauge in re-charging the MVAC should be discontinued because it is not a proper indicator of the level of the system refrigerant charge. In addition, the following instructions need to be included on the container label: (1) the engine must be running, (2) set the A/C system to maximum cooling with the fan on high, (3) an explanation of the can shaking procedure to achieve a properly charged system, and (4) an explanation for determining when a container is empty. This last instruction would include minimal liquid movement from inside the shaken container and a temperature rise of the container.

Emissions from Small Containers

There are two types of small containers available on the market: the screw-and-perforate (S&P) and the valve-equipped (V). According to the laboratory leakage measurements, new S&P type containers have an insignificant advantage over the V type containers prior to their use in re-charging a MVAC.

After use, the V type containers showed little difference in leak rate when compared with the new V type containers prior to use. Leak rate measurements were also carried out on S&P type cans with different charging assemblies installed. In two of the five cases, the kit equipped with the "push-button type" assembly resulted in emission increases of greater than 100 g/yr after use. In addition, this type of charging assembly released refrigerant during the re-charging process. In comparison, all charging assemblies with the shut-off valve increased refrigerant emissions by less than 0.3 g/yr after opening and closing the valves.

***Recommendation*:** Prior to use, the leak rates from both V type and S&P type containers are very low. However, the design of the charging valve and hose assembly and its interface with the S&P type container may have a significant effect on the emissions from the small containers of automotive refrigerant. The "push-button" type charging kits for the S&P type cans should either be banned or re-designed to reduce refrigerant emissions during and after usage.

Professional Servicing

CEP staff conducted a field survey of professional A/C shops by taking in a vehicle with an intentionally under-charged MVAC to observe the procedures that the technicians followed and their diagnosis of the system performance.

The first check ups included: (1) verification of the air temperature coming out of the vents in the cabin, (2) actuation of the compressor clutch, (3) measurement of the low and high pressures with the A/C on, (4) identification of the refrigerant in the system using an electronic analyzer, and (5) verification of the pressure inside the A/C loop by pressing the HP or LP Schrader valves. The figure to the right shows the frequency of the different types of checks done by the professional technicians. Note that DIYers as well as professionals check the ventilation air temperature while the other checks require the expertise and equipment of a professional technician.

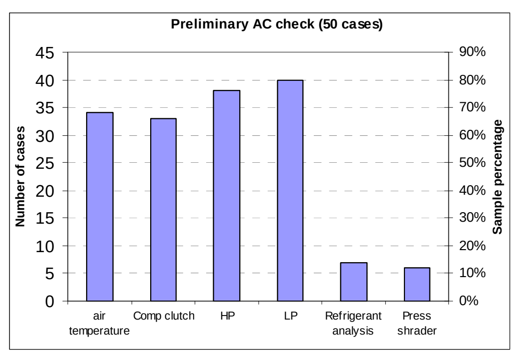


Figure b: Method of diagnosis of the sample of professionals

Followed by the system checks, the technicians diagnosed the system problems and recommended a course of action which consisted primarily of re-charging the MVAC system with refrigerant in over 90 percent of the cases. In almost 70 percent of the cases, the technician recommended that a leak search be carried out although this was only done in approximately 75 percent of these cases. There is some degree of variation in the check-up, diagnosis and recommendations performed by the technicians.

Professional Servicing with Recovery and Recharge Machines

About two-thirds of the professionals used automated recovery and recharge machines. This equipment is essential for limiting refrigerant emissions during servicing, provided the recovery is performed down to an absolute pressure of 4 psia. It was also observed that few professionals verify the refrigerant charge specified by the car manufacturer.

Different types of couplings are used in connecting the recovery and recharge machines to the MVAC systems. The usage of certain types of these couplings results in lower emissions of refrigerant. Standard testing should be performed on all couplings with the results published in order to promote the use of the ones with lower emissions.

Many fully automated recovery machines evacuate after recovery. A significant amount of refrigerant may be released during the evacuation process because if recovery stops at an absolute pressure around 14 psia. These emissions could be reduced by continuing recovery until a lower pressure is reached.

Recommendations: All professionals should use recovery and recharge machines in servicing MVAC systems. The professional technician should make a systematic leak search before refrigerant recovery when the saturating pressure is measured in the MAC system. When performing an A/C service, the technician should ensure that the manufacturers' specified refrigerant charge is used and, upon completion of the service, a tag or sticker should be placed under the hood indicating the date of service. The low-pressure threshold for refrigerant recovery should be set at 4 psia so that more refrigerant is recovered from the MVAC system.

Professional Leak Search

Twentysix technicians performed the leak check using the following methods:
(1) controlling the pressure rise after evacuation, (2) detection of UV-sensitive dye in the refrigerant, (3) using an electronic leak detector, and (4) the inspection for soap bubbles on a pressurized MVAC system. The majority of the technicians used the detection of UV dye with the electronic leak detector being used to a lesser degree.

The UV dye method is the only one that can be performed by the non-professional, because the other techniques require a professional's expertise and equipment. It should be noted that none of the technicians who participated in the study were able to detect a refrigerant leak even though CEP staff was aware of a very small leak at the expansion valve. The observations on professional leak detection concerning the necessary time lag between charging the dye and making a possible diagnosis of a leak is confirmed by laboratory tests which are described below.

The comparison of three detection methods at the CEP laboratory shows that the usage of a fluorescent lamp with UV dye is comparable or superior to either an electronic leak detector or the use of a soap solution on a pressurized MVAC system with an inspection for bubbles. The UV dye method has the capability of detecting a leak flow rate as low as approximately 6 g/yr after 11 hours.

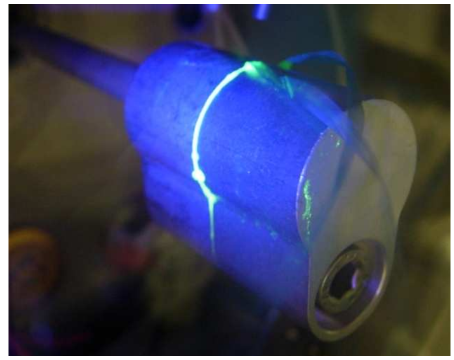


Figure c: Visualization of leak by UV dye.

Recommendation**:** A UV dye should be included in the refrigerant when the MVAC is charged during vehicle manufacture. This would give service technicians a simple means of identifying leaks.

Costs of Professional and Non-Professional Servicing

From the survey of professional shops, the cost for diagnosing a MVAC problem ranges from no charge to $20. For a professional diagnosis and re-charging with a recovery and re-charge machine, the cost ranges from approximately $50 to a little over $200. This may or may not include a leak inspection depending on the shop. If the professional shop performs a diagnosis and a recharge using small containers or a bottle of refrigerant, then the cost is under $100 according the shops that were checked. It should be noted that only a small number of professionals gave a diagnosis or incorrect recommendations concerning the servicing/repair of the MVAC. For non-professional servicing/re-charge, the cost of the refrigerant container and the charging assembly may range from $15 to $40 depending on the circumstances. The non-professional servicing may provide a major cost savings for the consumer if the only problem is a low-refrigerant charge.

However, it should be remembered that professional servicing does provide an added value over non-professional servicing. Professional technicians specialize in servicing/repairing MVAC systems and possess the expertise and equipment to effectively perform their duties. The potential added values include: (1) correct diagnosis of failure, (2) effective leak search, (3) use of a recovery & recharge machine, and (4) capability of repair.

Leak Rates from New MVAC Systems

The annual leak flow rates (LFRs) of MAC systems of the five most sold cars in California have been measured according to the methodology defined in the EU regulation 706/2007. The initial annual leak flow rates of those five MAC systems are of the same order of magnitude as those measured on European and Japanese cars. The average annual LFR of new systems is in the range of **10 g/yr ±4**. MVAC systems with double evaporator systems may have higher leak rates because of the extra connections, although two of the tested systems did have double evaporators.

Additional testing was conducted on one of the MAC systems. The system was mounted on a test bench, running continuously over 7 hours with a fixed leak rate of 1.5 g/min. Cooling performance data indicated that about 50% of the refrigerant charge has to be lost before the system ceases to perform adequately.

Recommendations: The refrigeration circuit of MAC systems should not require any servicing during the first 7 years because “regular” leaks are low unless there is some sort of catastrophic failure in the system. It is recommended that additional research work be conducted in order to analyze the wear and degradation of compressor shaft seals over time. This would lead to a greater understanding of why and when MAC systems become significantly more emissive.

An Alternative Approach for Do-It-Yourself MVAC Servicing

In re-charging a MVAC with a small container, the DIYer connects the charging hose assembly to the small can and the low-pressure service valve and shakes the can while charging the system until the can feels empty.

In using an automated R&R machine, an individual would connect the blue hose to the low-pressure service valve, connect the red hose to high-pressure service valve, push the button, and return approximately half an hour later after the completion of recovery and re-charge.

If you compare these two procedures, the use of an automated machine is simpler.

Figure d: Automated Recovery and recharge machine.

It would be possible to allow DIYers to continue recharging their MVAC systems without using the small containers of automotive refrigerant. Instead of buying small cans, DIYers could rent the use of a recovery & recharge machine at an auto-parts retailer. This approach would be similar to an individual inflating the tires on his automobile. A person does not buy a compressor to do this operation but typically goes to a gasoline service station. In addition, a DIYer could perform a leak check on his MVAC by renting a UV lamp from the auto-parts retailer. This would be a relatively simple process If UV dye is included with the refrigerant charge at the factory when the vehicle is being manufactured. The dye could also be injected by either a professional or a DIYer using a small can with dye.

Recommendations: Instead of using small containers to perform non-professional servicing, the DIYer should use a recovery & recharge machine that would be rented at auto-part stores. DIY individuals should perform leak checks on their systems. This would be feasible by charging refrigerant with UV dye at the factory, and auto-parts stores offering UV lamps for rent. In the interim, dye can be charged either by professionals or non-professionals.

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[EUR07] Règlement (CE) n° 706/2007 de la Commission du 21 juin 2007 établissant conformément à la directive 2006/40/CE du Parlement européen et du Conseil les dispositions administratives relatives à la réception CE des véhicules ainsi qu'un essai harmonisé pour mesurer les fuites de certains systèmes de climatisation.

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Abbreviations and acronyms

Abbreviations

AC	Air conditioning
DIYer	Do-it-yourselfer
ELD	Electronic leak detector
HFC	Hydrofluorocarbons
HP	High pressure
IS	Infrared spectrophotometer
LFR	Leak flow rate
LP	Low pressure
MAC	Mobile air conditioning
MACS	Mobile air-conditioning system
MVAC	Motor vehicle air conditioning
OT	Orifice tube
S&P	Screwed & perforated
SB	Soap and bubbles
SC	Small can
SCU	Small can user
SUV	Sport utility vehicle
TxV	Thermostatic expansion valve
UV	Ultraviolet

Acronyms

CARB Californian Air Resources Board
CEP Center for Energy and Processes