

# **Final Report**

## **Establishment of Leakage Rates of Mobile Air Conditioners in Heavy Duty Vehicles**

### **Part 1 Trucks**

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## Summary

On behalf of the EU Commission, this study establishes empirically the annual leakage rate of mobile air conditioners (MACs) in trucks for the use-phase of the vehicles. The approach consists of measurements of the bigger part of use-phase emissions, called "regular leakage". Regular leakage takes place gradually from intact MACs. This is quite different to "irregular leakage", attributable to system failures caused by internal or external reasons, often by accidents.

From July to November 2006, 271 measurements were carried out in Germany on trucks of the seven EU relevant brands, from model year 2000 onwards. The measuring sample should come close to the EU wide MAC-equipped truck fleet by models and makes, age, usage pattern, mileage, refrigerant charges, etc. The age of the MACs to be measured should not exceed seven years.

The measurements were made at 12 vehicle pools. For every MAC it was determined how much of the initial (norm) refrigerant charge was still in the system, and the deficit was related to the time elapsed since the vehicle's first registration. The assessment of the refrigerant deficiency in each MAC followed a dedicated Measurement Protocol which was in principle identical to that which was developed and used for establishing the leakage rate of MACs in passenger cars, in 2002/2003.

The most important results of the analysis are:

1. Based on the measurements, the EU wide average leakage rate of MACs in trucks is estimated to be 87.8 grams per year, with an error band of  $\pm 8.9$  grams at a confidence level of 95 percent. Expressed as percentage of the original refrigerant charge this equals 8.3 percent/year, with an error band of  $\pm 0.8$  percent.
2. The annual leakage rate (grams/year) is not constant over time. There is indication that newer systems of up to 35 months in use show higher leakage rates per year than older ones (36<sup>th</sup> to 88<sup>th</sup> months in use). However, the statement that leakage rates generally diminish with increasing age is too risky from a statistical point of view given the very small number of cases in the upper age categories.
3. Although the absolute leakage rates differ widely between the seven makes from 70.2 to 153.5 in grams/yr., these differences are not significant statistically. The uniformity of leakage rates of MACs from different truck makers is confirmed when the leakage rates are expressed as a percentage of the initial charges. These figures show a limited spread ranging from 7.3 to 11.5 percent, annually.
4. MACs with different charges lose an equal percentage of their refrigerant per year. As the norm fills vary widely from 700 to over 1,450 grams, smaller charged MACs (700-750 grams) were found to have a significant lower leakage rate in grams per year than bigger charged systems. Average loss per year is 58 grams from smaller charged MACs, and 87-123 grams from larger systems. From this it follows that a MAC design for trucks that reduces the refrigerant charge would contribute substantially, to reducing HFC-134a emissions from this source. The scope for reduction in overall regular emissions through charge reduction is estimated at 30% - if every MAC had a charge of only 750 grams.

5. The annual mileage of the trucks tested varies widely from 89,810 km/year to 196,382 km/year, if the quarter of cases with the lowest mileage is compared to the quarter with the highest values. The difference in annual leakage rate is much smaller, ranging from 72.5 grams (1<sup>st</sup> quarter) to 101.9 grams (4<sup>th</sup> quarter), and is statistically not significant. In conclusion, the influence of annual mileage on leakage rates of MACs in trucks is quite small – and it is even smaller on percentage leakage rates.

The results of this study need to be compared with other HFC-134a emissions that occur during the lifetime of the air conditioner.

In addition to the regular emissions established in this study, "irregular" emissions have to be considered also in the use-phase of a truck. The author of this study estimates "irregular" emissions at roughly 30 grams. Adding "regular" and "irregular" emissions and assuming that the expected lifetime of a truck is ten years, the expected average greenhouse gas emission from a truck mobile air conditioner in the EU is about 1.5 tonnes<sup>1</sup> of CO<sub>2</sub> equivalent over the use-phase.

These emissions need to be complemented by HFC-134a emissions before the vehicle has been taken into use, the service emissions and the end-of-life emissions, as well as CO<sub>2</sub> emissions due to the increased fuel consumption as a consequence of operating the air conditioner. In conclusion, while "regular" HFC-134a emissions are likely to be the single most important source of greenhouse gas emissions from mobile air conditioners in trucks, it is also important to estimate the amount of other HFC-134a and CO<sub>2</sub> emissions to understand the full climatic impact of these mobile air conditioners.

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<sup>1</sup> (0.088 kg + 0.030 kg) \* 10 \* 1,300 = 1,534 kg. (The GWP of HFC134a is 1,300.)

## I. Introduction: Focus on Regular Leakage Rate

In the framework of the EU climate protection goals, the European Parliament and the Council of the EU passed Directive 2006/40/EC relating to emissions from air-conditioning systems in motor vehicles. This Directive of 17 May 2006 provides a gradual phase-out of the high global warming refrigerant HFC-134a from mobile air conditioners (MACs) of passenger cars and light commercial vehicles.

In this context, the European Commission (EC) is reviewing the use of HFC-134a in MACs of buses and trucks which requires as a first step obtaining knowledge about the leakage rates. The purpose of this study, part I, is to fill this knowledge gap as regards trucks so that the EC has reasonably accurate data on current emission levels and so enable it to make empirically based projections of emission levels beyond 2010 if no additional policies and measures are undertaken.

### I.1 Empirical survey based on proven Measurement Protocol

While the leakage rates of passenger cars were measured in 2003<sup>2</sup>, no such information exists for trucks, yet. Overall, the losses of HFC-134a occur during (i) the manufacturing of the gas at the chemical plant, (ii) the charging of the MAC in the vehicle factory, (iii) the normal use of the vehicle and its air conditioner, (iv) the service of the air conditioner, (v) accidents and (vi) at the end-of-life of the vehicles when the MAC is dismantled. The EC specified that the first step was to establish the leakage of HFC-134a during the operation of trucks, i.e. when the air conditioners are used (use-phase leakage rate).

Like the 2003 EC passenger car MAC study, the survey on trucks concentrates on the bigger part of the use-phase emissions which is called "regular leakage".

Regular leakage or emission takes place gradually from undamaged, functioning air conditioners. It is a steady refrigerant loss through sealing, hoses, connections, valves, etc, from every MAC over the entire use-phase. This is quite different to "irregular leakage", attributable to system failures caused by internal or external reasons, often by accidents.

Generally, the leakage rate is defined as grams of HFC-134a that have leaked in one year from a vehicle with an air conditioner. The annual regular leakage rate is derived by relating the refrigerant loss measured (the difference between recovered quantity and standard ex-works charge), to the time elapsed since the vehicle's first registration<sup>3</sup>. From the estimates for every individual MAC, an average leak rate is calculated from the total of different leakage rates.

Empirical estimation of regular emissions from MACs of road going vehicles requires appropriate measurement procedures and equipment. The methodology to be

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<sup>2</sup> Final Report on Establishing the Leakage Rates of Mobile Air Conditioners, prepared for the European Commission, DG Environment, by Winfried Schwarz and Jochen Harnisch, April 2003. [http://ec.europa.eu/environment/climat/pdf/leakage\\_rates\\_final\\_report.pdf](http://ec.europa.eu/environment/climat/pdf/leakage_rates_final_report.pdf)

<sup>3</sup> The calculation is done by dividing the difference in grams by the number of months since first registration, and the calculated amount is multiplied by 12.

applied had been outlined beforehand in a special report on behalf of the Commission<sup>4</sup>. A Measurement Protocol (and a questionnaire) which describes the equipment and specifies the individual steps of the measurement cycle had already been developed and used for establishing the leakage rate of MACs in passenger cars, in 2002/03. This Protocol was adjusted to the specific conditions of truck MACs.

## I.2 Other approaches to establishing leakage rates of vehicle MACs

Empirical studies on MACs of real road-going vehicles had not been undertaken before 2002; estimates of leakage rates relied on expert judgments or laboratory measurements. After 2002, some empirical surveys were conducted on air conditioners in passenger cars. Specific studies on emissions from truck<sup>5</sup> air conditioners were not available by 2006.

In 2002, Siegl (2002) extrapolated results from a 2-day diurnal test of 28 light duty vehicles to the average vehicle lifetime in order to achieve an average R-134a emission rate from an AC equipped vehicle. After the 2002/2003 EC-study on passenger car MACs, a Swiss team (Stemmler 2004) estimated HFC-134a emissions based on measurements of emissions from real road traffic in a highway tunnel in the area of Zurich. Another tunnel test was performed in California 2005 with a similar approach (CARB 2005). Although dealing with real road-going vehicles, all these tests were laboratory-like "snapshot" tests that cannot directly determine long-term emissions from MACs in normal use. Nonetheless, they are useful for supplementing and crosschecking results from other surveys.

In 2004, CARB (California Air Resources Board) presented the results of a large-scale survey that, inter alia, evaluated recharging data of 12,500 vehicles from nine different fleets. They concluded that the leakage rates were of the same order of magnitude as found in the EC passenger car study 2002/2003.

In the context of EU legislation on fluorinated greenhouse gas emissions, another empirical approach was used. Clodic (2005) reported results of a measurement survey on a fleet of 30 cars whose MACs had been filled with exactly defined refrigerant quantities before their use in normal in road traffic. After twelve months the same MACs were tested on the remaining refrigerant level. This approach is impressive, especially because of the achievable high data precision. The latter is necessary because the special purpose of the approach is implementation of leakage tests for type approval under Directive 2006/40/EC.

In preparation of the EC truck MAC study and again in the discussion of the draft final report on the stakeholder meeting in January 2007, some industry experts proposed that this study should also use an approach based on two, "before and after"

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<sup>4</sup> Study on the Methodology to establish Leakage Rates of Mobile Air conditioners in Light and Heavy Duty Vehicles (Trucks and Buses), prepared for the European Commission, DG Environment, by Winfried Schwarz, June 2005. [http://ec.europa.eu/environment/climat/pdf/fin\\_rep\\_mac\\_bus\\_truck.pdf](http://ec.europa.eu/environment/climat/pdf/fin_rep_mac_bus_truck.pdf)

<sup>5</sup> Trucks in this study are heavy-duty vehicles. Pickups, SUVs, and vans, which are called trucks in USA, are not considered here, although such "trucks" are included in empirical surveys performed in California 2004 ff.

measurements. The sample should be increased to some hundred units in order to achieve a high degree of representativity, comparable to this study.<sup>6</sup>

Reservations, however, arose as to whether the operating conditions of such a truck fleet in the 12 months after MAC charging would be free of artificiality. As a consequence, measurements of trucks with MAC charges older than one year were excluded although seen necessary. It was recognised that an extremely high input of work force in logistics was necessary to accompany such a fleet over an entire year. Nobody was ready to pay per one vehicle up to 20 times more than the existing Measurement Protocol requires, even after its adaptation to truck specific conditions. Given these financial constraints this approach was not adopted.

In the light of the preceding discussion about the data accuracy achievable with the approach applied in this study we need to be careful with the results of measurements and of statistical analysis presented in this report. The data in this report is based on field measurements with highest-achievable certainty of  $\pm 10$  grams at most. It should be kept in mind that the objective of the survey is not the assessment of leakage rates of individual MACs. This survey primarily aims at establishing the average annual leakage rate of the EU wide MAC-equipped truck fleet.

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This report is structured as follows: Chapter II presents the selection criteria that the surveyed sample shall meet pursuant to discussion with truck makers and to specifications set by the EC. Chapter III addresses accuracy issues of the measuring approach. Chapter IV discusses how close the measured sample meets the selection criteria for a representative survey in respect to makes and models, usage patterns, age, mileage, and MAC charges. To eliminate biases, the sample is corrected by removal of already measured truck MACs that do not fulfil these criteria. The concluding Chapter V presents and discusses the statistical results of the analysis of the measured data.

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<sup>6</sup> If the proposed study was limited to 30 vehicles only, the accuracy of the results would be poor because the sample would not reflect enough real-world situations. Systematic error (bias) would be too high then. According to clear statistical definitions, accuracy means the agreement between the true value and the measured observations. This is independent on precision which means exactness of measurements. Only the latter would be higher in the proposed twice-measurement approach.



## **II. Selection Criteria for the Measuring Sample**

The specification of the Commission to have regular leakage rates established for the present European MAC equipped truck fleet is fundamental for the structure of the study.

This raises the question of representativity and of selection criteria for the measuring sample. To the extent possible, the sample must cover the parameters that influence the leakage rate. Industrial experts from truck makers substantially contributed to establishing the criteria which were included in the Study on the Methodology of June 2005.<sup>7</sup> In the following sections these criteria are presented.

### **II.1 Focus on trucks over 16 t GVW**

Light Commercial Vehicles (LCVs) and passenger cars (PCs) are of the same kind in essential technical features inclusive of their MACs. All components of the refrigeration circuit are fixed to the vehicle front section, and the refrigerant piping only requires a minimum stretch of flexible lines. Thus, leakage rates established in the earlier EC study can be transposed to LCVs.

The situation is different for trucks from roughly 6 t GVW upwards (pursuant to EU classification: upper range of N2, complete N3 category). Compared to PCs and LCVs, trucks have drives based on diesel engines with fewer revolutions per minute (< 2,200 rpm rated speed) and higher displacement (from 4 litres up to over 16 litres).

The crucial factor for MAC design of EU trucks is that the driver's cabin is not behind the engine compartment but sits above it. This makes movable ("tilting") cabins necessary, and consequently the MAC system requires fairly long refrigerant lines (4-5.5 metres), with comparatively long stretches (up to 30%) of flexible hoses to connect chassis-mounted compressor and condenser with cabin-integrated evaporator (DCAG 2005).

The longer flexible lines and significantly higher refrigerant charges in trucks would suggest the likelihood of higher leakage than that from passenger cars. It is evident that the specific features of trucks require special empirical investigation into MAC leakage from trucks over 6 t GVW.

In 2005, new registrations of trucks over 6 t GVW are estimated to amount to approx. 370.000 units, in the EU-25. The vast majority (more than 75%) are trucks over 16 t GVW, with 250.000 units in the EU-15, and additional 30.000 in the new EU Member States (ACEA 2006). Trucks from 6 to 16 t make up less than 25% of the total.

The annual sales figures by make leave it open to which extent the trucks were equipped with MACs. Publications on MAC installations (MAC quota) by country or

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<sup>7</sup> Minutes of the Kick-Off Meeting, Brussels, 2 February 2005, Annex III to the "Study on the Methodology to Establish Leakage Rates of Mobile Air conditioners in Light and Heavy Duty Vehicles (Trucks and Buses)" for the European Commission, DG Environment, by W. Schwarz, June 2005.

by make are not available for the entire EU. From interviews with experts it was ascertained that MAC quotas do not differ significantly between the individual EU truck makers.

Based on data from their bestselling model ACTROS, DaimlerChrysler estimate that this quota has oscillated constantly around the 90 percent mark, since 2000<sup>8</sup>. If this is true, the MAC quota of trucks over 16 t is about 2.5 times higher than of trucks below 16 t (only 26% to 35% from 2000 to 2005). Consequently, heavier trucks over 16 t represent some 90% of the EU wide truck MACs in operation.

Therefore, the survey on truck MAC leakage concentrates on vehicles over 16 t GVW without taking a notable risk of a bias.

## II.2 Age of truck MACs

It is the purpose of the survey to establish the average leakage rate of relatively new "second generation" MACs. The preceding Study on the Methodology recommends measuring only relatively new air conditioners. The logic is that the leakage rate of modern MACs would be a fairly good proxy of the average leakage rates for the years to come, especially for 2010 and beyond.

Therefore, only vehicles younger than seven years, i.e. from model year 2000 onwards (first registration at the end of 1999) shall be tested.

## II.3 Truck makes and models

The EU-study on PC-MACs has shown that notwithstanding the fundamental identity in design of MACs by make there were wide differences in leakage rate by makes. A similar result cannot a priori be ruled out for truck MACs. Therefore, the relevant truck makers should be represented in the sample as far as possible with their real share in the market or, better, with their real share in the EU wide inventory of MAC equipped vehicles.

Compared to passenger cars, the number of truck makers and models in the segment over 16 t GVW in the EU is of manageable size. The market and truck fleet is supplied by just seven manufacturers, and all their vehicles are made in EU plants. In the truck segment of from 16 to 40 t GVW, there is virtually only one model per manufacturer of relevance on the market, and at least this should be represented in the sample<sup>9</sup>.

Medium trucks, which take part both in the light and in the heavy segment, are of minor numerical importance, and the sample does not need to include this category.

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<sup>8</sup> Pochic, Jean-Pierre, DaimlerChrysler AG, Commercial Vehicles Division, Environment and Energy, Dpt. TPE/EVA, Communication to Öko-Recherche, Stuttgart, 1 June, 2006.

<sup>9</sup> For comparison, the EU study on PC-MACs dealt with 102 models from 21 manufacturers.

The EU truck makers are shown in Table 1 with their current (2006) best selling heavy truck model. The sample should include all these models together with their immediate predecessors if there were any sold in the 2000-2006 period.

**Table 1: EU truck makers and their main models over 16 t GVW - by name and country of assembly, 2006**

<b>Manufacturer</b>	<b>Main Model &gt; 16 t</b>	<b>Countries of Assembly</b>
MERCEDES	ACTROS	Germany
DAF	XF 105*	Netherlands
VOLVO	FH series	Belgium, Sweden
IVECO	STRALIS**	Germany
MAN	TGA***	Germany, partly Austria
RENAULT	MAGNUM	France
SCANIA	R-series****	Netherlands, Sweden

\* Predecessor 2000-2005: XF 95; \*\* predecessor 2000: EuroStar; \*\*\* predecessor 2000: F2000; \*\*\*\* predecessor 2000-2005: L-series.

The table gives additional information on the countries where they are manufactured or at least assembled. The assembly plant is of interest because it is the plant where the MACs are installed.

#### **II.4 Usage patterns and mileage**

It was agreed at the 2005 Brussels expert meeting with EU truck makers, and was incorporated in the EC specifications for the study that the survey shall be based on vehicles from several truck pools. A number of ten fleets were recommended. The sample shall be large enough, i.e. include at minimum 150 truck units so that it can at least partly reflect the wide variety of usage conditions the vehicles are subject to as well as the annual mileage they cover. As the mileage indicates driving time, the strain on MACs caused by running engines can be considered indirectly on this basis.

#### **II.5 No further details on technical parameters**

Given proper representation of different truck models, the sample will simultaneously consider different refrigerant fills of the MACs. They range from 700 to more than 1.500 grams. These differences in charges indicate that the overall technical MAC design significantly differs from make to make and from model to model.

It must be pointed out that the study first of all aims to establish the EU wide leakage rate of truck MACs in grams of HFC-134a per year. Further statistical evaluation is limited to interconnections of the leakage rate with those parameters that serve as selection criteria for the sample such as makes, models, age of vehicle, refrigerant charge, mileage, etc. as listed above, and are easily accessible to the survey team.

In-depth analysis of the influence of specific MAC design and of technical parameters like compressor type, pipe materials, workmanship of components, tightness of

valves or seal rings, etc is outside the scope of this study, as this is clearly a matter for truck and MAC makers themselves<sup>10</sup>.

## **II.6 Impact of climatic conditions on the investigation**

All measurements of the survey are carried out in Germany, which is located in the centre of the EU. Climatic differences within the EU are not considered.

In the light of the study on passenger car MACs, which could not find any connection between climate and leakage rate within the EU, climatic conditions are unlikely to play a major role in leakage of truck MACs, either. Additionally, long distance trucks from Central Europe are usually driven both to southern and to northern parts of Europe so that they are regularly subject to different ambient temperatures that influence the running time of the MAC.

Not least for budget reasons, this study did not validate if the findings from MACs in passenger cars can be applied to trucks in this way.

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<sup>10</sup> As in the case of the study on passenger cars, the Commission offers to give all measured data to the companies if they wish so, so that they can analyse them in terms of their own interest. Naturally, information about individual vehicles will be given only to the manufacturer in question.

### III. Issues of Measurement Accuracy

Estimation of regular emissions requires appropriate instruments to measure the remaining HFC filling of vehicles with undamaged MACs. In the study, each individual leakage rate is established by determining the deficit of the current refrigerant level against the initial (norm) fill in grams, and by subsequent relation of that difference to the vehicle's age in years since the first registration. Accuracy issues arise in determining the deficiency, i.e. both the current level in a MAC at the measuring time and the initial level from factory filling.

#### III.1 How exact is the extracted refrigerant measured?

The measurements were carried out with four units of commercially available recovery stations from A'Gramkow Waeco. In order to increase the number of tests per day, often all of them were running at the same time. These mobile stations recovered the refrigerant content from MACs under standardised conditions like minimum duration 20 min, suction pressure 0.6 bar abs., minimum ambient temperature 10°C. To enhance the accuracy of the subsequent weighing, the insufficiently reliable built-in scales of the recovery units were not used, but the entire recovery unit was put on external scales before and after recovery.

A Measurement Protocol (and a questionnaire) which describes the equipment and specifies the individual steps of the measurement cycle had already been developed and used for establishing the leakage rate of MACs in passenger cars, in 2002/03. As to trucks, the determination of the refrigerant level did not raise grave questions. Thus, the adjustment of the Measurement Protocol was kept within reasonable limits.

Details on the Measurement Protocol can be found in Annex I of this study.

#### III.2 How much refrigerant can be extracted from a MAC?

The next accuracy issue relates to the question to what extent the actual refrigerant content in a MAC corresponds to the refrigerant quantity extracted and measured by means of the aforementioned equipment. Is this equipment capable of recovering the MAC content completely, or is there an unrecoverable amount, e.g. some HFC-134a remains dissolved in the oil, which remains in the system.

During the 2002/03 study on MACs in passenger cars, it was found that the service stations were able to extract most of the refrigerant out of the system but a definite quantity remained. The un-recoverable remainder was measured at 20 grams, on average. The respective qualification tests were carried out at Volkswagen's Wolfsburg plant on MACs that had been filled exactly with the norm fill beforehand. In statistical analysis of the passenger car MAC data, the refrigerant deficit of field-measured recovery from norm fill was generally reduced arithmetically by that remainder in order to avoid overstatement of real leakage. In practice, in every measuring case a constant correction factor of 20 grams was added to the recovery.

Consequently, one of the Commission's specifications for the adjustment of the truck Measurement Protocol was to assess the truck-specific remainder that recovery stations are unable to extract. The size of this remainder should serve as correction factor to achieve true levels of leakage rates. For that, a couple of test measurements at fresh-filled truck MACs were recommended. Facing the higher refrigerant charge of truck MACs the remainder, and thus the correction factor was assumed to be a bit higher than in case of passenger cars, at least of the same order of magnitude.

### **III.3 What follows from initial MAC filling over the norm charge?**

The size assessment of the unrecoverable remainder that serves as correction factor of the measured recovery does not include the solution of the third accuracy problem, namely the precision of the initial factory charge.

If ample resources of time and money allow a two-measurements-approach, this problem does not arise. If two measurements are carried out in intervals of e.g. twelve months, the first for the initial fill and the second for what is left after one year of operation, the amount of the initial fill is no source of uncertainty for the measuring team. After all, they themselves have charged the MAC initially.

Who applies a one-time measurement approach as used in this study is faced with the fact that he can control only the accuracy of the "second" measurement. The initial charge is out of his control. He has to accept and to rely on the specification of the norm fill given by the vehicle makers. The norm fill is the only available information about the initial fill, and thus the only possible benchmark the recovery can be compared with in order to determine the refrigerant deficit.

In the study on passenger cars, the quantitative identity of norm fill and initial fill was generally assumed. Carmakers had declared that the charging equipment was set to norm fill; small deviations were not one-sided and would be balanced out on average. Identity of initial fill with norm fill given, application of a correction factor in the size of the unrecoverable remainder allows sufficiently accurate determination of the deficiency between initial charge and current level of refrigerant in the MAC.

In the course of the field measurements of truck MACs, in 2006, it was repeatedly discovered that in MAC systems less than 12 months old that the recovery level was barely below the specified norm fill, and sometimes even above it. Statistical application of a correction factor of, say, 30 grams would have transformed such small refrigerant losses into refrigerant gains, in 37 cases. Negative leakage rates, however, are useless for further analysis.

Doubts did not emerge on whether there is an unrecoverable remainder in truck MACs as was the case in passenger car systems. However, serious concern arose whether in case of trucks the ex-works charges are actually identical to the norm fills indicated on MAC labels and specified in service manuals. The assumption that not only in individual cases but systematically a definite quantity of refrigerant was charged into new-installed truck MACs, beyond the norm was emerging. Apparently, a bit more than necessary was acceptable, even though the norm-fill might be optimum charge in technical terms. If overcharging was a real practice, it would no

longer be a surprise that service stations repeatedly recovered full norm charges from very new MACs.

This raises the question if under conditions of general and equal initial charging beyond the norm, this norm can be used as a benchmark in the determination of the refrigerant deficit.

The following considerations help answer this question.

When testing new ex-works MACs with initial charge beyond the norm, the measured recovery will no doubt be lower than this initial charge because of the unrecoverable remainder. At the same time, it will be higher compared with the level if exactly the norm had been charged. Increase in recovery is equal to overcharge in the system. In other words, if the MAC is filled over norm, the recovery increases by the same surplus amount. Measured recovery still misses the initial fill by the remainder but it misses the norm charge by less, i.e. by remainder minus overcharge.

*From the equation "recovery = norm fill + overfill – remainder" follows that recovery is norm fill minus remainder if there is no overfill.<sup>11</sup> If overfill is equal to remainder, the two quantities cancel each other out, and recovery and norm fill become the same.*

From this it follows that the norm fill can continue serving as benchmark in this study if the correction factor is no longer the unrecoverable remainder but the difference between overcharge and this remainder, which is a smaller quantity.

As by definition the difference between measured recovery and norm fill is equal to overcharge minus remainder ( $recovery = norm\ fill + overfill - remainder$ ), the correction factor simply results from a comparison of measured recovery with norm charge. One does not need to know real sizes of initial fill or remainder. The only important point is to find out at fresh-filled MACs how close the measured recovery comes to the norm fill. The qualification tests must be carried with the equipment used in the study itself because the remainder is equipment-specific too.

### Conclusion

The approach applied in this study to establish leakage rates essentially relies on the use of norm fills as benchmarks, which in turn requires a correction factor accounting for incomplete refrigerant recovery. Although general and equal initial fill of truck MACs over the norm is assumed, the correction factor can be ascertained by comparison of measured recovery with norm fill. The qualification tests of factory filled new MACs does not require laboratory-like measuring conditions. The usual equipment (recovery stations and scales) is sufficient. The only fundamental condition is that the trucks for the measurements are so new that their MACs had no occasion to lose refrigerant, so far.

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<sup>11</sup> The 2003 Volkswagen qualification tests at passenger car MACs can retrospectively be seen a special case of the general equation. Overfill was zero. Thus, recovery missed the norm fill exactly by the remainder. (Recovery = Norm fill + Zero – Remainder).

### III.4 Qualification tests with four new trucks

In November 2006, at two truck sellers such qualification tests were conducted on four new trucks. On November 4, at a German IVECO centre one Stralis truck with a norm fill of 750 grams of its MAC was tested. On November 7, at a German MERCEDES centre three trucks were measured, two Actros with MAC norm fills of 1,100 grams each, and one Axor with norm fill 1,200 grams. All the four vehicles had been assembled about one month ago and showed a mileage according to the distance from the assembly plant (300 – 450 km) only. Following the drivers of the vehicles, the MACs had not yet run before the measuring day.

Details on the tests and their results are shown in Tables 2 and 3.

Summarizing the results of these measurements, it can be stated that less refrigerant than the norm fill was recovered in none of the four tests. Two times, the norm was met exactly; two times the recovery was higher, by 60 grams and 90 grams, respectively. Obviously, the remainder was compensated by factory overcharge.

The conclusion drawn for the statistical analysis is that no correction factor needs to be applied; more precisely, the correction factor to be applied is zero.

**Table 2: First Qualification Test at one IVECO Truck. Iveco Süd-West Nutzfahrzeuge GmbH, Center Dietzenbach, Germany (Hesse)**

Date	4 November 2006
Ambient Temp.	10°C
Truck Brand	IVECO
Truck Model	STRALIS AS260S42
Vehicle Style	Swap Platform
GVW	26 t
Engine Power	420 hp
Assembly Plant	Ulm, Germany (Distance from Center ~ 315 km)
Odometer	314.1 km
Assembly Date	12 Oct 2006
Arrival at Center	2 Nov 2006
Age at Test	21 days
VIN	WJMM1E2NSH4321807
Norm Charge	750 grams
Service Station	RHS 640
Test Begin - End	11.40 – 12.15
Weight before	70.96 kg
Weight after	71.71 kg
Recovery	0.75 kg
Diff. to Norm	± 0 kg
Proved by	Thomas Borgert (M-TEC, Ibbenbüren). Winfried Schwarz (Öko-Recherche, Frankfurt/M). Martin Kaiser (Iveco Süd-West Nutzfahrzeuge, Dietzenbach)



**Table 3: Second Qualification Test at three Mercedes Trucks. DaimlerChrysler AG, Branch Network OstWestfalenLippe, Center Gütersloh, Germany (North Rhine-Westphalia)**

Date	7 November 2006		
Ambient Temp.	15°C		
Truck Brand	Mercedes		
Truck Model	Actros 18.36	Actros 18.46	Axor 18.24
Vehicle Style	Swap Platform	Tractor	Tractor
GVW	18 t	18 t	18 t
Engine Power	360 hp	460 hp	240 hp
Assembly Plant	Wörth, Germany (Distance from Center ~ 450 km)		
Odometer	448.9 km	433.5 km	451.5 km
Assembly Date	27 Sept 2006	29 Sept 2006	12 October 2006
Arrival at Center	1 Nov 2006	1 Nov 2006	1 Nov 2006
Age at Test	34 days	32 days	20 days
VIN	WDB9300371L174665	WDB9340331L169694	WDB9505371L177478
Norm Charge	1.10 + 0.05 kg	1.10 + 0.05 kg	1.20 + 0.05 kg
Service Station	RHS 640	RHS 650	RHS 640
Test Begin - End	14.45 – 15.15	15.00 – 15.30	15.45 – 16.15
Weight before	70.79 kg	71.36 kg	71.43 kg
Weight after	71.95 kg	72.46 kg	72.72 kg
Recovery	1.16 kg	1.10 kg	1.29 kg
Diff. to Norm	+ 0.060 kg	± 0 kg	+ 0.090 kg
Proved by	Thomas Borgert (M-TEC, Ibbenbüren). Winfried Schwarz (Öko-Recherche, Frankfurt/M). Lars Siemund (DaimlerChrysler Branch, Gütersloh).		

Admittedly, extrapolation of data obtained from just four vehicles to the final measuring sample of 234 units is risky. Even if all MERCEDES and IVECO truck MACs were systematically charged over the norm, the situation could be different at the other five EU based truck brands.

Nevertheless, general overcharging is the only cogent explanation for the extremely small refrigerant losses that repeatedly occur in the measuring sample – in trucks from two more makers with relatively high representation in the sample. Even if refills that have been carried out since first registration are an alternative and imaginable explanation, these trucks are too new for having repairs and topping up.

On this issue, there is a communication from the EU market leader MERCEDES, which can serve, with some reservations, as testimony of general overcharge in the sector.

On November 20, 2006, the following information<sup>12</sup> was given on the reality of charging truck MACs in the biggest EU truck plant, Wörth in Germany. We take the liberty of citing and presenting it in the following box.

<sup>12</sup> Pochic, Jean-Pierre, DaimlerChrysler AG, Commercial Vehicles Division, Environment and Energy, Dpt. TPE/EVA, Information from DaimlerChrysler AG, Status 20 November, 2006 (German).

**Information from DaimlerChrysler AG**

Nominal specifications for refrigerant charging of Actros and Axor series from the production plant

1. Quantities specified by Truck Development

From development department the following filling quantities are specified for Actros and Axor series.

Actros Type C 93 without stationary air conditioner	1,100 gr + 50 gr.
Axor Type C 95	1,200 gr + 50 gr.

2. Setting of specified values at charging equipment in production plant

Based on must values and allowed tolerances the specifications for charging are the following for the charging equipment in the assembly plant

Actros Type C 93 without stationary air conditioner	1,125 gr.
Axor Type C 95	1,225 gr.

3. Deviation of charges on filling

Because of process and measuring conditions (see below), on filling of vehicles discrepancies occur between default and actual values. As a rule, these deviations vary +/-15 gr. around the set point of the charging equipment.

Reasons for deviations from the default value are

- Metrology tolerances of the charging station
- Variation in temperature and pressure of refrigerant supply system
- Refrigerant loss when detaching filling adapter from service valves

State 20 November 2006

Jean-Pierre Pochic

DaimlerChrysler AG

From this information it emerges, that systematically 25 grams (average) more than the norm charge are specified for filling MACs of MERCEDES trucks.

In order to prevent too low charges, it is specified to fill 25 grams over the norm so that possible deviations downwards are compensated at any rate. As in reality deviations upwards are equally possible, the long run mean of the actual charge will be 25 grams over the norm.

These 25 grams are in the range of a likely remainder that is not recoverable with standard equipment as used in the EC truck MAC measurement programme.

Thus, the charging practice of the largest truck manufacturer in the EU supports the approach of this study as regards a correction factor for measured leakage rates. Overcharging is the only explanation of the possibility to recover the norm fill completely from new installed MACs by means of usual recovery equipment.

*Initial charges above the norm are achieved because truck makers want to be on the safe side. This, however, does not mean that they intend a refrigerant reserve for regular leakage, i.e. to put off the breakdown of the MAC for lack of refrigerant. To be on the safe side means the intention to charge the norm without fail. As filling equipment meets any specified charge only with unpredictable deviations due to varying charging conditions in the factory, charging beyond the norm is the only guarantee that the norm charge is met on all accounts.*

The norm refrigerant charge as indicated and labelled by truck makers is the benchmark the measured recovery has to be compared with in order to assess the amount of leakage.

## IV. Composition of the Measured Sample

This chapter analyses how close the actually measured truck MAC sample comes to the selection criteria established for the sample as presented in the second chapter of this report. Apart from the fundamental criterion that the MAC systems have never been refilled beforehand nor are completely empty, the most important requirements for the sample to be met are the following.

- Measurements of a sufficiently large number of MACs of trucks over 16 t GVW, to be conducted at several vehicle pools
- Variety of operating conditions the vehicles are subject to such as load, distance of covered routes, annual mileage in kilometres
- Multitude of truck makes and models
- Age of the vehicles; only trucks from model year 2000 onwards shall be considered to attain clues for the leakage rate of 2010 and beyond.
- Different refrigerant charges of MACs.

As selection criteria are rejection criteria, in this chapter a correction is carried out to eliminate cases that have turned out not to fit the sample after the first measurement. This refers to MACs that are too old or show extraordinary large or small refrigerant charges.

### IV.1 Number of Trucks over 16 t GVW from several vehicle pools

From 15<sup>th</sup> July to 4<sup>th</sup> November, 2006, in twelve truck pools in Germany 271 trucks of GVW over 16 t were measured for the refrigerant level of their MAC, according to the Measurement Protocol. The vehicle pools are located in Western (North Rhine-Westphalia) and Central Germany (Rhine-Main area). The measurements took such a long time because the vehicles were accessible only on Saturdays.

The trucks were not made available by truck makers; the measurements were carried out independently of them. In seven cases, forwarding companies made their vehicles available once the author of this study had directly spoken to them. In five cases, truck sellers gave information on vehicle pools of their brand, so that the author could contact the pool managers for MAC tests. In all, one in three contacted truck keepers with sufficiently large number of vehicles consented to MAC testing. Persuading fleet managers to allow measurements was made easier by the offer to check gratis each MAC on the proper charge and to top it up in case of refrigerant deficiency.

From 300 MAC systems originally to be tested, about 10% or 30 units were ruled out before measuring because of pre-damage or strong suspicion of it. Information on previous repair or refill came either from the pool manager or from drivers. Herein it proved advantageous that the measurements were conducted at active truck fleets and not at second-hand dealers who usually do not know much about the previous history of the vehicles they are displaying. The information about the MACs was

supplemented by sight control of the measuring expert who could identify some pre-damages when components like condenser, dryer or pipes in the front of the vehicle evidently differed in age and state from the remaining system. It should be noted that inside components like compressor or evaporator were not inspected.

## IV.2 Usage patterns of the selected trucks

The twelve truck pools of the sample show big differences in transported load and length of the routes of their vehicles.

It can be seen from Table 4, that the majority of the MAC tested vehicles belong to big haulage companies that forward general cargo for a multitude of customers, in long-distance traffic. This applies to companies no 1, no 3, no 5, and no 7 with altogether 151 (55%) tested vehicles.

Of almost the same quantitative importance are big specialised agencies that work exclusively for one customer. No 4 transports refrigerated produce of a meat factory, and no 6 forwards products from a factory making agricultural machines throughout Germany. No 9 delivers (for Lufthansa) air freight in every country of Europe. In all, 94 measurements (35%) were carried out at vehicles from these seven pools.

**Table 4: Usage patterns: Load and action radius of the sample trucks**

No of company	Load	Distance	Tested trucks	av. km/y per truck
1	General cargo	international	21	183.777
2	Waste, Bulk	local	6	53.320
3	General cargo	international	29	118.352
4	Meat (refriger.)	national	53	129.879
5	General cargo	international	89	148.001
6	Agric. machines	national	32	145.690
7	General cargo	international	10	158.683
8	Earth, sand	local	6	79.281
9	Air freight	international	10	202.054
10	Wooden material	local	4	52.583
11	[Truck dealer]	unknown	5	76.693
12	Industrial food	regional	6	106.898
Total			271	140.071

A further 22 (8%) vehicles from smaller, specialised truck pools were also tested: five trucks for waste transport (company no 2), six construction trucks for earthworks (company no 8), four trucks for wooden materials (company no 10), and seven delivery trucks for products of food industry (company no 12).

Finally, there are five tested vehicles from a used truck centre (no 11), whose former usage is unknown.

Table 4 presents not only the above mentioned data but also the average annual mileage of the trucks in those twelve pools.

Not unexpectedly, trucks in long distance traffic (for general cargo and air freight) cover the most kilometres per year, from 118.000 to 202.000. This is ten times the annual mileage of passenger cars. However, trucks in medium distance traffic (pool 4

and 6) run scarcely less, with mileages of 130.000 and 145.000 km, respectively. Only the mileage of trucks for local and regional routes is substantially lower, ranging from 50.000 to 80.000 km/year. This is half the mileage of long distance trucks.

Certainly, usage patterns of trucks do not facilitate direct conclusion on the leakage rate of their MACs. This is, of course, not the function of this overview. Its purpose is only to check whether the measurement sample accounts for the real usage variety of heavy trucks over 16 t GVW or if it reflects only a partial aspect of their operation. Obviously, the sample cannot be blamed for one-sidedness.

### IV.3 Make and model mix of the sample

As shown in Chapter II, in the truck segment of from 16 to 40 t GVW, there are only seven makers with virtually only one model of relevance on the market, and so it is in the sample. As in this study the market shares of MAC equipped trucks are equated to the market shares of trucks in general, at least from 2000 onwards, the make and model mix of the sample should keep with the real mix on which ACEA reports annually for the entire EU.

Table 5 shows for each make in the category over 16 t GVW the representation in the sample, both in numbers and in percent. For comparison, the right column gives for each make the real EU market share as average value for the last seven years. Thus, it can be read off how close the measurement sample is to the reality of the EU inventory. Bear in mind that only trucks from model year 2000 onwards are included.

**Table 5: Truck makers' representation in the sample and in the reality of the EU**

<b>Make</b>	<b>Number in Sample</b>	<b>% in Sample</b>	<b>Market Share EU</b>
DAF	41	15	14
IVECO	13	5	11
MAN	76	28	16
MERCEDES	82	30	21
RENAULT	8	3	11
SCANIA	21	8	14
VOLVO	30	11	14
	271	100	100

The Table shows that the measurement sample accounts for all the seven brands. However, a row-by-row comparison of the figures in column 3 with the respective figures in column 4 proves that only for two brands, DAF and VOLVO, does the sample meet reality fairly well. As to the other makes, the sample clearly shows a preponderance of MAN (28 to 16) and MERCEDES (30 to 21). This preponderance goes along with clearly lower percentages of SCANIA (8 to 14), IVECO (5 to 11), and RENAULT (3 to 11).

These deviations are due to the heavy weight of MAN and MERCEDES in their home fleets Germany, where all the 271 measurements were carried out. Thus, the sample obviously mirrors the German brand mix better than the EU brand mix. In Germany, the market shares of MERCEDES, MAN, DAF and VOLVO are significantly higher than in the other EU countries. Therefore, in case of these four brands it was easier to find vehicle pools that were not only large enough but also run by managers willing

to cooperate – much easier than in the case of the relatively rare brands of IVECO, SCANIA, and RENAULT. Retrospectively, it would have been better to include all the seven brands by their proper share. However, unequal make representation in the sample can bias the average MAC leakage rate only if the different makes show different leakage rates with statistical significance. This will be seen in the final chapter of this report.<sup>13</sup>

#### **IV.4 Correction: Elimination of too old and of pre-damaged systems**

It is the purpose of the survey to establish the average leakage rate of relatively new "second generation" MACs. Therefore, only vehicles younger than seven years, i.e. from model year 2000 onwards (first registration at the end of 1999) should be tested. A further basic criterion that this study shall comply with is that all MACs to be tested are still undamaged and work properly. Any indication of extraordinary refrigerant charge either too low or too high, must lead to exclusion from the sample.

##### Removal of eight old MACs

The measuring expert was instructed to include in the sample only vehicles that were first registered from the end of 1999 onwards. After measuring, eight vehicles turned out to be older. This happened because the truck papers were not yet available before the measurements, or the papers were not handed over until some days after. These eight trucks were discarded from further analysis.

##### Removal of five leaky MACs

In spite of visual inspection and control by the measuring expert, in some cases the recovered refrigerant quantity was so small that only a leak, invisible to naked eye, could have caused the high deficit against the norm fill. As a rule, a deficiency of more than 65% of the initial charge is assumed not to be the result of regular but of irregular leakage. Accordingly, five MACs that were already measured were removed from the sample.

##### Removal of eighteen overcharged MACs

In the sample eight MACs older than 12 months were found with higher charges than the norm fill ("negative" leakages). In these cases it was very likely that the MAC had already been refilled to compensate for irregular leakage during the use-phase. These overcharged MACs were not further considered.

There are, however, a further ten MACs aged less than 12 months, for which a refrigerant level was measured that was 10 to 40 grams higher than the norm fill. Previous refill is not likely; obviously, in the factory these MACs were charged, whatever the reasons, with an extraordinary high surplus beyond the usual upper tolerance.. As said in Chapter III of this report, it is an essential prerequisite of this approach to take the norm fill as benchmark for leakage assessment. Therefore, these ten overcharges were eliminated from further analysis, too.

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<sup>13</sup> It should be noted that unequal sample representation of particular parameters can be corrected by weighting the found parameter values not with their sample shares but with their real shares. This, of course, presumes that the latter are known. This is the case for the make structure.

### Removal of six refilled MACs

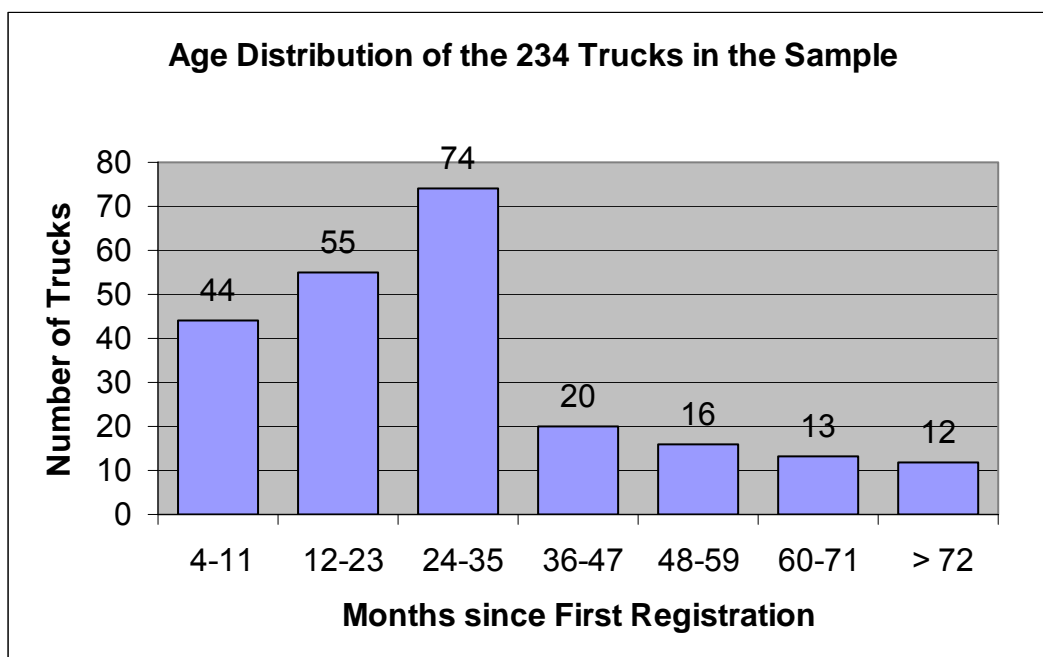
Systems with very small refrigerant deficits against the norm fill belong to the sample. Thus, five relatively new MACs with leakage = 0 remain in the sample. If, however, systems are older than one year and show annual deficiency of just 1% or even less, the assumption is that they were topped up in the time from first registration. Amongst the measured MACs there are six units with such extraordinary high charges. They are eliminated like the systems with real overcharge.

As a result of the elimination of eight trucks being too old and of further twenty-nine trucks showing extraordinary MAC charges (too low or too high), the sample decreases from the original 271 cases to 234. Only these fulfil the selection criteria of this study. In the following, 234 truck MACs are valid units and subject to further consideration including statistical analysis.

It should be added that every truck make is involved in this correction from outliers, some brands to higher and others to a lesser degree.

### IV.5 Age distribution

The corrected sample of 234 trucks shows an age distribution, as presented in the graph, which requires some comment.



**Figure 1: Age distribution of the corrected sample. Three quarters of the measured trucks are younger than three years.**

First three quarters of the trucks (173 of 234) are less than three years old.<sup>14</sup> The average age of the sample is just 29.2 months. The question may be raised whether

<sup>14</sup> There are three truck pools in the sample with not even one single vehicle older than three years (companies no 5, 9, and 10, as per Table 4). These three pools include 40% of the sample trucks.



there is a strong bias in the sample; for, one could have expected that all the six columns in the graph should be approximately the same size.

However, sector experts including pool managers of the sample, state that for industrialised EU countries three years is the real limit for long-distance trucks in the forwarding industry. It is a vital condition for this business to operate vehicles fit for service throughout the whole year and capable of running several hundred thousand kilometres without accidents. Such a high degree of reliability can only be provided by relatively new vehicles. Therefore, forwarders tend to exchange their trucks after three years, at least, on condition they can afford it financially.

Yet, there are enough foreign buyers of three-year-old trucks. They usually purchase directly from the operators so that a real market for second hand trucks with specialised dealers does not exist in practice<sup>15</sup>. Demand for used trucks is still high enough in less industrialised countries outside the EU. However, even EU countries with low purchasing power take on such vehicles from wealthier member states.<sup>16</sup>

On the whole, the age structure of the sample is obviously not untypical of the situation in the EU.

#### **IV.6 Mileage of the vehicles**

Amongst others, mileage indicates running time of the engine which is considered to strain the MAC and to affect leakage rates.

Sub IV.2, mileage is already addressed with its differences between the twelve vehicle pools (uncorrected sample). Here, for the corrected 234-sample average mileage since first registration, mileage per year and distribution over the totality of the vehicles is presented briefly.

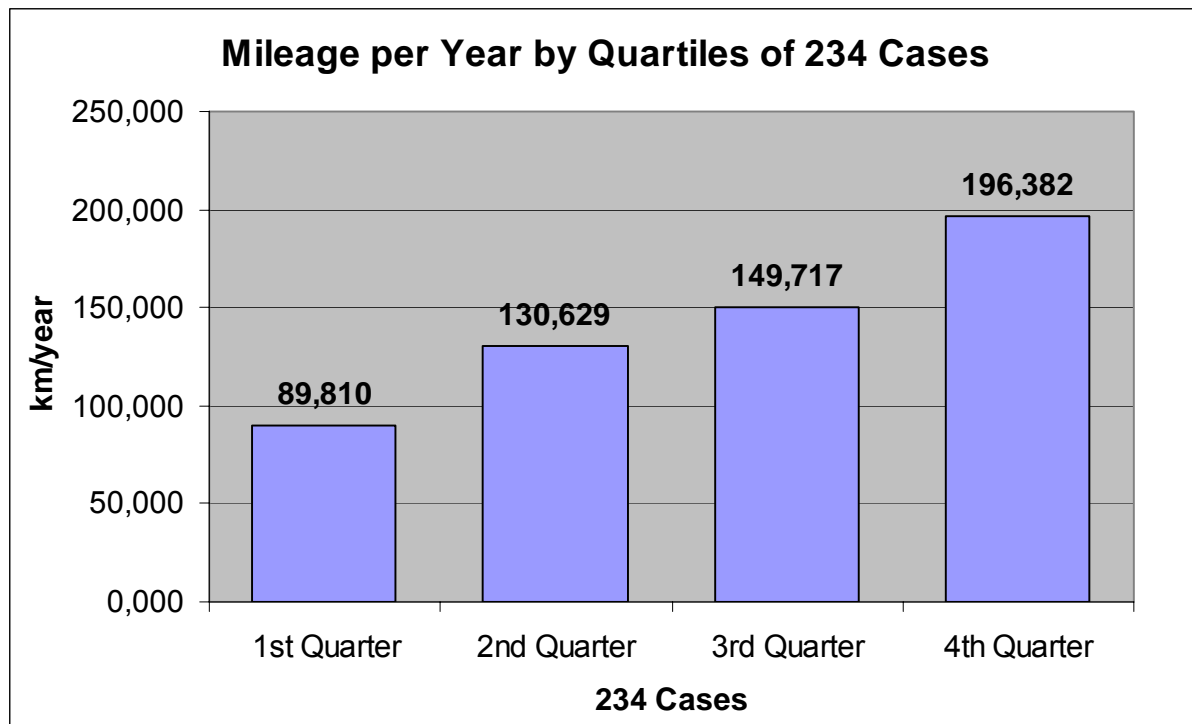
Average mileage per truck is 329,403 km; mileage per year is 141,822 kilometres. To compare this annual figure with real data, statistics on the mileage of the EU wide fleet were required; such data could not be found in the course of this study. Nonetheless, rule of thumb which appears to be used by sector experts was that trucks cover ten times the mileage of passenger cars.

As the latter is about 13,000 to 15,000, the sample value of 140,000 may be considered relatively representative.

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<sup>15</sup> In this context, the question had sorted itself out if active trucks from pools or used trucks from second-hand dealers should be measured in this project.

<sup>16</sup> Typical of German trucks is drain off to Eastern Europe.



**Figure 2: Annual mileage of the 234 sample trucks. The vehicles show wide spread in kilometres per year when split into quartiles.**

Figure 2 graphically shows for the sample the wide spread in mileage. The average value 89,810 kilometres per year for the first quarter of cases (58 of 234) is just half the average value of the fourth quartile (59 cases) with 196,382 kilometres per year. To a certain degree this difference reflects different usage patterns.

#### IV.7 Refrigerant charges of the MACs

Each truck model has only one MAC charge regardless of differences in engine power, GVW, or further technical vehicle properties. Therefore, one needs to consider only a few different charges when estimating their average size.

Overleaf Table 6 shows the truck models of relevance for the EU fleet as well as for the (corrected) sample. The last column contains the refrigerant charges with the levels this study refers to as norm fills. They widely range from 700 g to 1,700 g for truck models being sold during the 2000-2006 period.

Only five of the seven truck makers declare the charge on labels in the vehicle. To get the specifications of the others inquiries of authorized garages were necessary.

For a particular year, the average MAC charge of the trucks sold to the EU market can approximately be achieved by weighting the model-specific MAC charges (as per Table 6) with the EU market shares of the respective truck makers (as per Table 5).

**Table 6: Norm fills of the MACs in the sample by truck models, 2000-2006**

Make + Model	Cubic	First VIN in corrected Sample	Norm Fill
DAF XF 95	12.6	XLRTE47X50E575717 (2002)	700
DAF XF 95, XF 105	12.9	XLRTE47X50E665263 (2005)	950
IVECO EuroTrakker	13.8	WJMJ3JSS00C073951 (2001)	1700
IVECO Trakker	12.9	WJME2NUS20C154269 (2005)	750
IVECO EuroStar	9.8	WJMM1VSK004218232 (2000)	1700
IVECO Stralis	12.9	WJMM1VRP00C142785 (2005)	750
MAN F2000	12.0	WMAT32ZZZYM286155 (2000)	950/1150
MAN M2000	6.9	WMAM41ZZ249121518 (2003)	950
MAN TGA	10.5	WMAH05ZZZ1G150886 (2000)	950
MAN TGA	10.5	WMAH05ZZZ2G155927 (2001)	900
Mercedes Actros	11.95	WDB9500461K470316 (2000)	1200
Mercedes Actros	11.95	WDB9302031K857988 (2003)	1100 + 50
Renault Magnum	12.8	VF611GTA000113609 (2002)	1500
SCANIA 94,124, 144 L	9, 12, 14	XLER6X20004410109 (2000)	1450 + 50
SCANIA R 420	12.0	XLER4X20005120324 (2005)	1235 + 50
VOLVO FH 12	12.1	YV2A4DBCX1B225202 (2001)	1200 ± 25
VOLVO FH 12	12.1	YV2A4CMAX2B314944 (2002)	1250 ± 50

In 2004, the average charge calculated in this way figured about 1,085 grams. One year later (2005), when SCANIA had introduced the R-series with 215 grams less, and DAF the XF 105 model with 250 grams more than the preceding models had in the MAC systems, the average charge slightly increased to 1,090 grams<sup>17</sup>.

In 2001, the respective value had been considerably higher, with 1,210 grams. This was due to the very high charge of IVECO EuroStar (1,700 g) – predecessor of Stralis (750 g); replacement of the circular tube condenser has lowered the MAC charge of IVECO's heavy-weight truck substantially.

Average value of the initial MAC charges in the corrected sample is 1,057 grams, over the entire 2000-2006 period. Sample value and real value are fairly close to each other so that the sample cannot be blamed for a bias in MAC charge.

<sup>17</sup> The IVECO Stralis, which is represented in the corrected sample first from 2005 onwards, was brought on the market in 2002, already. The IVECO construction truck Trakker came 2004.

## V. The Results: Annual Regular Leakage Rate of Truck MACs in EU-25

**Introductory remark.** The numerical values presented in this chapter should be interpreted with care. All of them are derived from field measurements of refrigerant differences between norm charges and recoveries, which show tolerances of  $\pm 10$  grams. This general uncertainty of measurement results is not reflected in the following figures. Decimal places shall not convey the impression of particularly high accuracy. They serve as indicators of the direction the deviations are likely to go.

### V.1 The average leakage rate per year in grams and percent

Table 7 gives the sample means of the data.

**Table 7: Means of the sample (n = 234)**

Norm charge per MAC	1,057 grams	GVW	21.1 t
Age of the MACs	29.2 months	Engine power	415 hp
Ambient temperature	22.4 °C	Annual mileage	141,822 km
Cubic capacity of engine	11.7 litres	Mileage	329,403 km

The annual regular leakage rate is derived by relating the refrigerant loss measured (as difference between recovered quantity and norm ex-works charge), to the time (by single months) elapsed since the vehicle's first registration.<sup>18</sup> From the estimates for each of the 234 MACs, an average of these 234 different regular leakage rates is calculated. The absolute value amounts to 87.8 grams/year (Table 8).

**Table 8: Annual Leakage Rate in grams of HFC-134a and as a percentage of norm charge**

	Valid n	Minimum	Maximum	Mean	Error Margin*
Grams	234	0	457	87.8	8.9
Percent	234	0	37.0	8.3	0.83

\* Margin of Error is 2 x Standard Error (2 x Standard Deviation divided by  $\sqrt{n}$ ).

The mean of 87.8 grams is estimated at a confidence level of 95 percent. As 1 Standard Error (SE) is 4.5, the 95 % confidence Interval is 87.8 g  $\pm$  8.9 g ( $\pm$  2 SE). Between 78.9 grams and 96.7 grams is the range within which the true mean of the population (MAC-equipped truck fleet in the EU) lies with a likelihood of 95%<sup>19</sup>.

The relative annual leakage rate is the percentage of the measured difference against the MAC's norm charge, which is annualised in the same way as above. It is found to be 8.3 % per year  $\pm$  0.83 %, thus ranging from 7.5 to 9.2 %.

Table 9 shows the effect of removing the outliers from the sample. The average annual leakage rate of all the 271 measurements (raw data) was 83.0 grams. The correction has not introduced a bias. After removal of the 37 outliers the average annual leakage rate (87.3 grams) is just 4 grams higher than in the beginning.

<sup>18</sup> The calculation is done by dividing the difference in grams by the number of months since first registration, and the calculated amount is multiplied by 12.

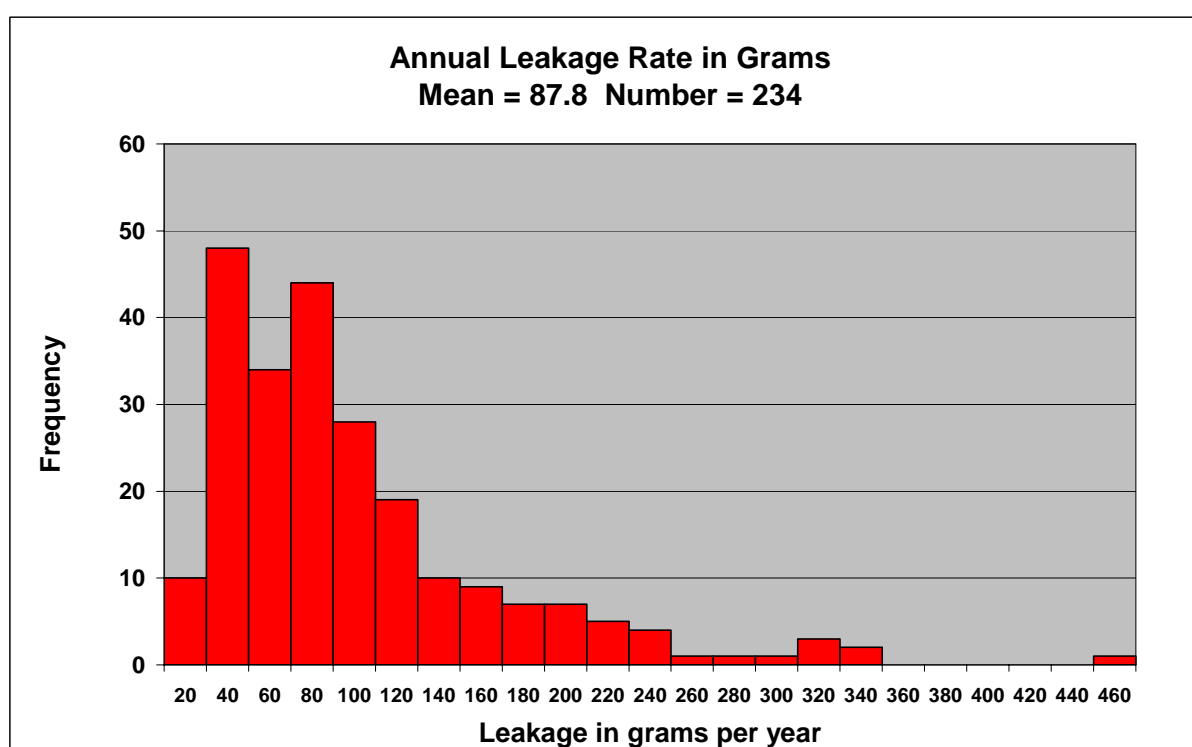
<sup>19</sup> The mean of the sample, of course, is only the mean of reality so far the analysed sample includes and reflects the real influencing factors on the leakage rate properly.

**Table 9: Steps of correction of the average annual leakage rate**

Step of correction	1. Raw data	1. Remove 8 too old	2. Remove 5 leaky	3. Remove 18 overfilled	4. Remove 7 refilled
<i>Number</i>	271	263	258	241	234
Leakage rate g/y	83.0	84.3	77.1	85.9	87.8
Leakage rate %	7.6	7.7	7.3	8.1	8.3

## V.2 The scattered profile of the individual annual leakage rates

The 87.8 grams/year or the 8.3 % annual leakage rate is an average calculated from widely scattered individual cases, compensating for major variations upwards and downwards. Figure 3 gives the individual annual leakage rates in grams/year by frequency columns in 20-grams-steps of from 0 to 460 grams.



**Figure 3: The 234 regular annual leakage rates in 20-gram-sections, by frequency. The average of the scattered leakage rates amounts to 87.8 grams.**

The structure of the 20-gram-bars is not very far from the shape of a normal distribution. With 89%, the vast majority of cases lie within the 0-180 gram span.

## V.3 Age dependency of the leakage rates

Figure 4 gives the scatter gram of the amounts of leaked refrigerant (without annualising) against months of use of trucks.

As expected, the older the vehicle the more HFC-134a has leaked from it. The graph also reflects the wide spread emission profile of the individual leakage rates, which the above figure expresses independently from truck lifetime.

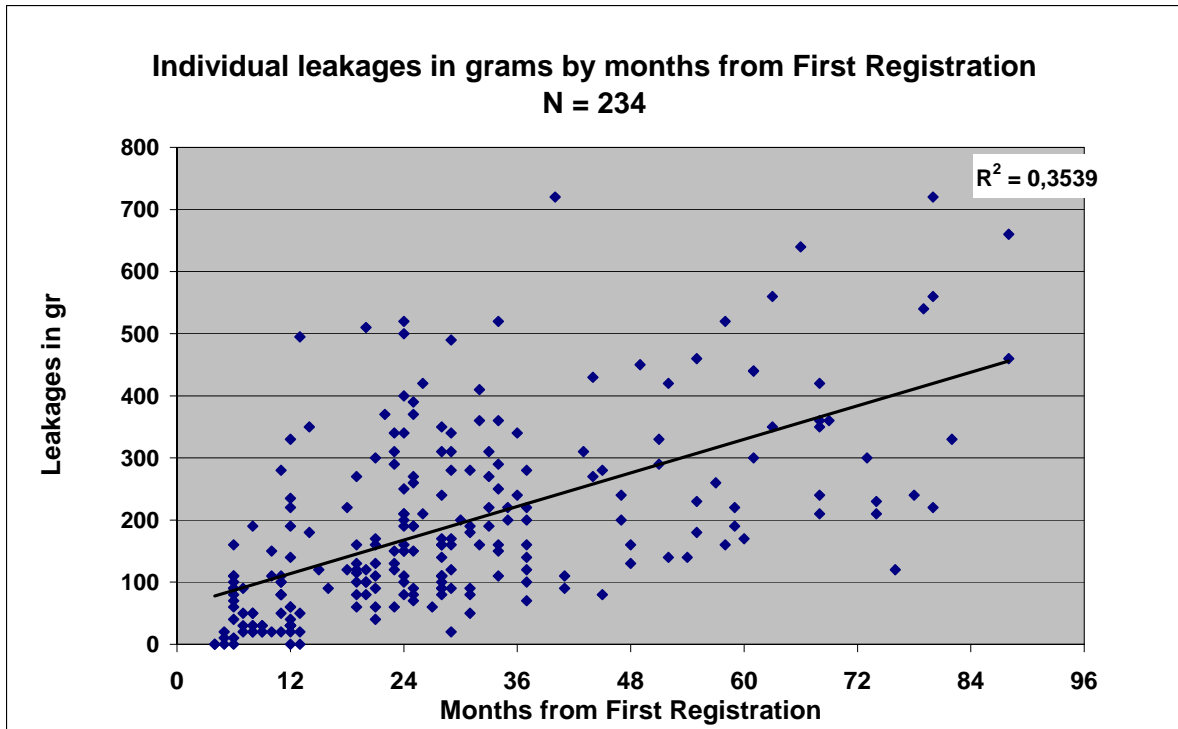


Figure 4: The MAC leakages in months since first registration. The data points of the 234 loss rates show a clear direction from bottom left to top right.

From the following Figure 5 which shows the absolute rise in the annual means of the leakage rates with increasing lifetime by subsequent years, the general dependency on the age of the MACs can be seen even clearer.

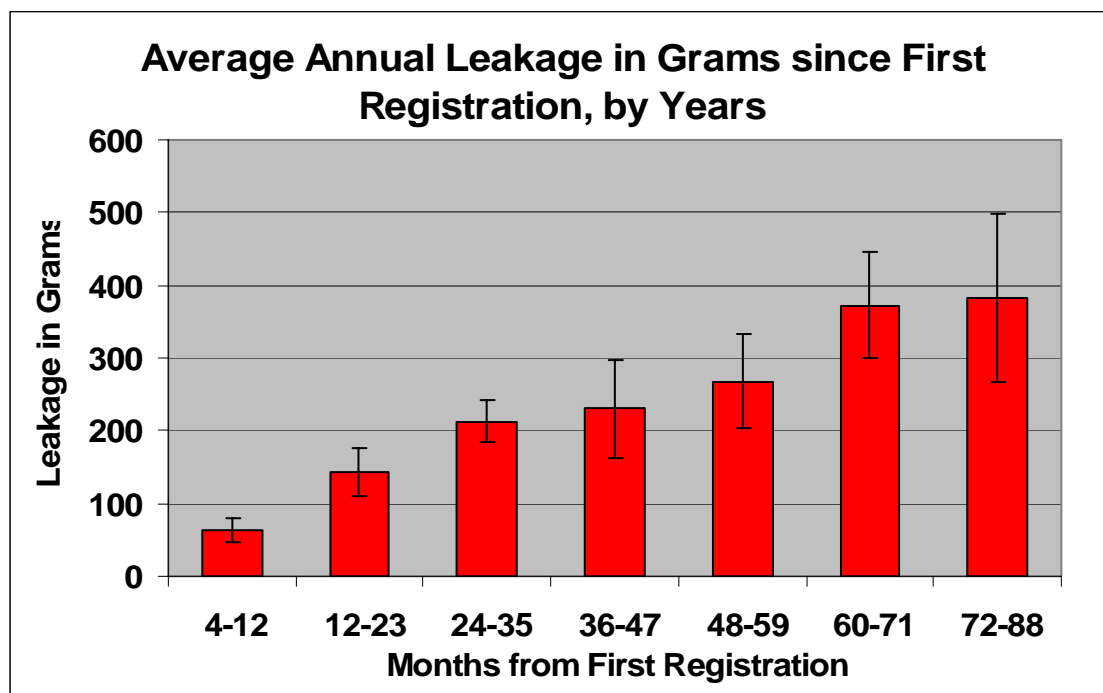


Figure 5: Annual means of leakage rates in absolute amounts, rising with increasing time by subsequent years from first registration.

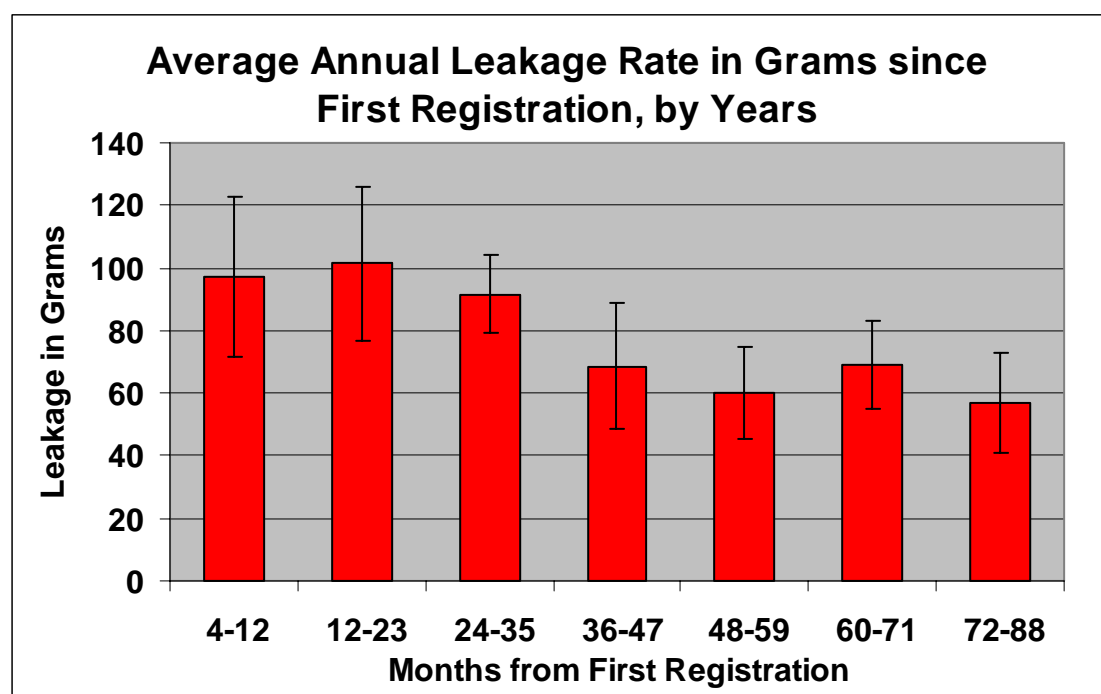
Although in both figures an overall upward trend is marked, the scatter gram reveals that refrigerant losses do not take an identical course in every single MAC.<sup>20</sup>

There are too many influencing factors. For instance, the duration of time for which individual systems remain switched on over the lifetime of a vehicle can be expected to vary widely, even in the same climatic region in Europe. Then, the run of a vehicle's engine (as it undergoes vibration and the development of heat), also varies widely, which can be easily read off from the differences in mileage per year. As shown in Chapter IV.6, average mileage of the first quarter of trucks is 89,810 km while the kilometres covered by vehicles in the top quarter averages 196,382, which is roughly twice as much. Looking at individual mileages, the lowest figure in the sample is 19,828 km per year; the highest is 436,275 km per year.

Another factor of relevance might be the usage patterns of the trucks in operation, which are not completely reflected in annual mileage. Certainly, long distance trucks running on straight and long motorways are not subject to the same strain as short-ranging delivery or even construction trucks in stop-and-go or off-road traffic.

Another factor would be the driver's personal driving habits, which will have varying stressful effects. Again, the way the MAC is operated by the driver and used has a part to play, and the ambient temperature co-determining a system's pressure is not the same for every unit. Moreover, the quality of workmanship in one MAC is not absolutely the same as in the next.

As an obvious next step one moves to the annual average leakage rates individually, in order to test their path along the years of the time-axis.



**Figure 6: Average annual leakage rates, by time from first registration. The values range 60 to 100 grs. Few differences are statistically significant.**

<sup>20</sup> The coefficient of determination  $R^2$ , which is a measure of the correlation between response variable and explanatory variable, is just 0.35 as shown top right in Figure 4. This means that 35% of the variation in leakage rates (response variable) can be explained by variation in time as of first registration (explanatory variable). The remaining 65% must be explained by other variables.

**Table 10: Average annual leakage rates in individual years of operation**

Year	1	2	3	4	5	6	7
<b>[Months]</b>	<b>4-11</b>	<b>12-23</b>	<b>24-35</b>	<b>36-47</b>	<b>48-59</b>	<b>60-71</b>	<b>72-88</b>
<b>Number</b>	44	55	74	20	16	13	12
<b>Leakage rate gr./y</b>	<b>97.1</b>	<b>101.4</b>	<b>91.6</b>	<b>68.6</b>	<b>59.8</b>	<b>69.0</b>	<b>57.0</b>
Error band grams	±25.4	±24.8	±12.6	±20.0	±14.7	±13.9	±16.1
<b>Leakage rate perc.</b>	<b>10.0</b>	<b>9.6</b>	<b>8.4</b>	<b>6.9</b>	<b>5.7</b>	<b>5.6</b>	<b>4.7</b>
Error band percent	±2.6	±2.2	±1.0	±1.5	±1.5	±1.0	±1.2
<i>Av. Age in months</i>	7.8	17.1	28.3	40.3	53.8	64.9	79.3
<i>Av. Charge grams</i>	970	1031	1088	978	1103	1235	1213

Figure 6 and Table 10 show, that the average annual leakage rate in the sample is not so constant over the time, as it could have been assumed from the presentation at the beginning of this chapter. The average leakage rate of 87.8 grams of HFC-134a per year is applicable only over the total of the seven years. By annualising the leakage rate it turns out that – for some reason – younger MACs seem to have a higher leakage rate than older ones.

The MAC leakage rate of the 1-3 year old trucks is evidently higher (101.4 - 91.6 grams per year) than in the subsequent four years (69.0 – 57.0 grams per year). Even though statistical evaluation reveals that the majority of differences are not significant, and most error bars overlap with each other, it must at least be noticed that compared with the MACs in the second and third year, both the five-year-olds and the seven-year-olds show significantly lower leakage rate levels.

Before attempting to find factual reasons for this phenomenon, it is considered advisable to check how reliable these low values effectively are. Table 10 shows that the numbers of annual cases are rather low from the fourth year onwards. This also applies to years 5 and 7, which exhibit differences in leakage rates compared to the first three years, which although minimal are significant in statistical terms.

From Chapter IV.5 on the age structure of the sample it is known that the sparse population of the age-groups beyond the first three years is not accidental but caused by sales abroad of used vehicles at a very early stage.

Further, it is well known that the likelihood of refills grows with increasing age of MACs. From Figure 5 it can be read off that in the third year of use the refrigerant loss already amounts to over 200 grams, on an average, which means even higher loss in some individual cases. Although the measuring technician was instructed to pick out only MACs never repaired or refilled before, it cannot be ruled out that one or two refilled systems were included in the sample and have not been eliminated in the course of the correction later on.

A closer look at both the fifth and the seventh year of the MACs in the sample reveals that the low level of their average leakage rate would instantly lose statistical significance if just one single system in an age group had its relatively high refrigerant charge from a previous refill of no more than about 300 grams.

Even though such a refill cannot be checked or proved retroactively, the risk that it has been carried at least in one case is considerably high. It is deemed so high that

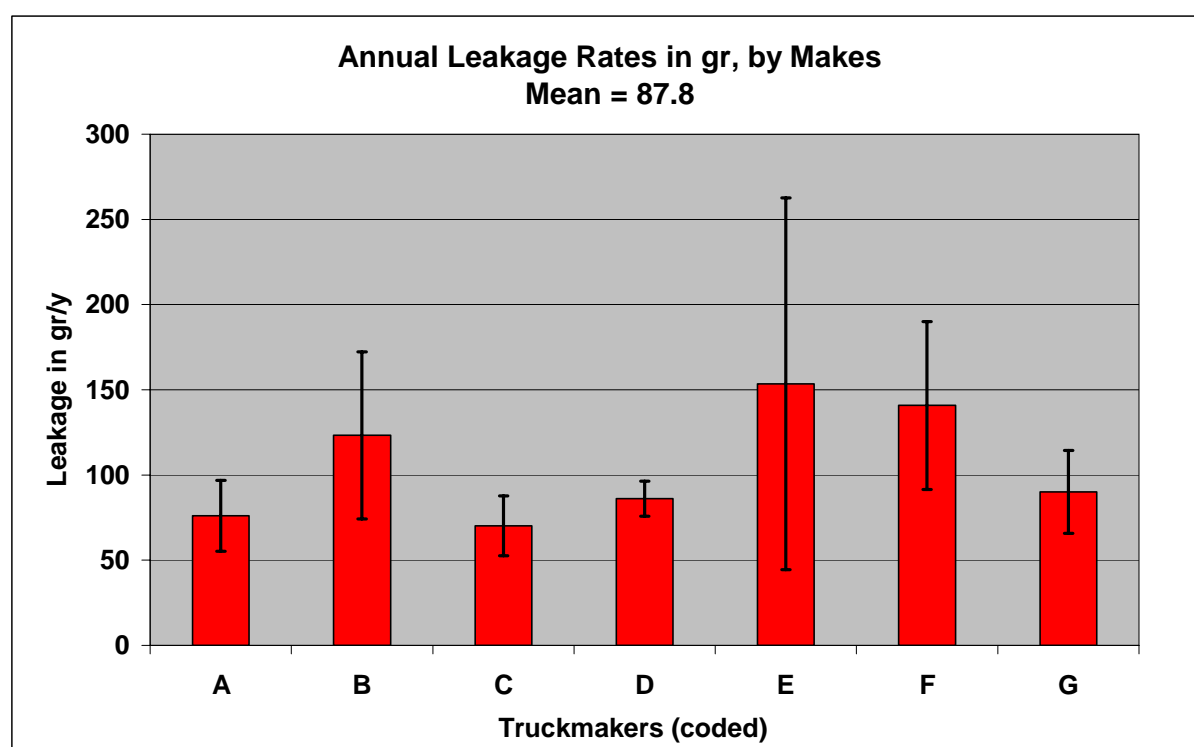


for reasons of reliability one cannot seriously derive the statement that leakage rates of truck MACs generally diminish with increasing age.

### V.5 Average annual leakage rates by truck make

Chapter IV on representativity also deals with the make composition of the sample. The question there is, how close the sample comes to the EU-wide MAC equipped truck fleet.

Wide differences between the individual annual leakage rates of the makes seem to exist (Figure 7 and Table 10). This is suggested by the wide spread in height of the columns for the mean values in Figure 7.



**Figure 7: Regular annual leakage rates by makes (coded). The mean values (columns) widely differ from each other, ranging from 70 to 153 gr. per make. Overlapping error bars, however, indicate that only one significant difference exists, between make C and F.**

While the average annual leakage rate is 87.8 grams/year the MAC leakage rates of three truck makers with fairly high numbers of units in the sample (A, C, D) are lower than this figure. On the other hand, there are three makes (B, E, and F) that show clearly higher leakage rates than the others way above the mean value.

In spite of the visible differences between the pure mean values, the overlapping error bars indicate that there are hardly any differences of statistical significance. The only exceptional case is the difference between makes C and F. C represents the maker with the lowest leakage rate of just  $70.2 \pm 18$  grams per year while F stands for the truck maker with a MAC leakage rate of  $140.8 \pm 49$  grams annually. The number of units with which F is represented in the sample is so small that again reservations towards premature conclusions seem to be indicated. For real

significance additional measurements were advisable not only of MACs from truck maker F but also from B and E.

**Table 10: Average annual leakage rates (LR) with error band (EB) by makes (coded)**

Make	A	B	C	D	E	F	G	All
LR gram	76.1	123.2	70.2	86.0	153.5	140.8	90.2	87.8
EB gram	±21	±49	±18	±10	±109	±49	±24	±8.9
LR %	9.2	11.5	7.7	7.8	10.2	10.3	7.3	8.3
EB %	±2.3	±6.7	±2.0	±0.9	±7.3	±4.0	±1.9	±0.8
Av. Age	26	45	23	27	24	33	47	29

*Explanation:* Different makes behind the codes are DAF, VOLVO, IVECO, SCANIA, MAN, RENAULT, MERCEDES – assigned to the code letters in a random manner. For confidentiality, the number of units per make and the charge are not made public.

Overall, existing alignments in leakage rates of MACs from the seven EU truck makers indicates a high degree of uniformity with respect to design and to quality of components and workmanship. This uniformity is confirmed by a look at the leakage rates in percent (Table 10). The figures show very narrow spread of from 7.3 (lowest value) to 11.5 (highest value) without any significance of differences. As percentages, the mean values are much closer to each other than in absolute terms.

## V.6 Average annual leakage rates by MAC charges

Under IV.7, MAC charges were presented with their variety in size from 700 grams to 1,700 grams. In 2005, the average size on the real EU market was 1090 grams. This is 130 grams less than in 2001. The spread has become smaller too with charges from 750 to 1,500 grams. The average charge in the sample is 1,057 grams.

Different sizes of MAC charges do not reflect bigger or smaller vehicles. All the seven truck models of relevance are similar in design and in volume of the engine compartment. Different-sized cabins do not affect the MAC charge, either.

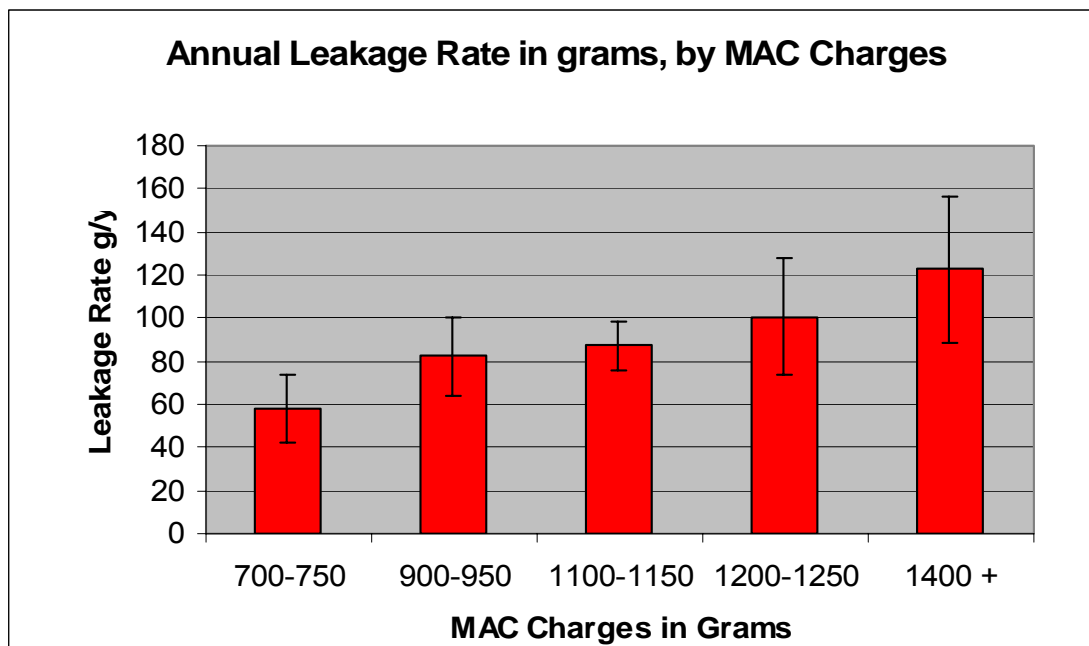
Here, the question is to what extent different refrigerant charges show different leakage rates – in absolute and in relative terms.

**Table 11: Average annual leakage rates by MAC charges, grams and percent**

Charge in grams	Loss gr/y	Error	Loss % /y	Error	Number	Age months
700-750	58	±16	8.1%	±2.1%	30	31
900-950	82	±18	9.0%	±1.9%	71	20
1100-1150	87	±11	7.9%	±1.0%	70	24
1200-1250	101	±27	8.2%	±2.2%	39	47
1250 +	123	±34	8.2%	±2.3%	24	40
Average	87.8	±9	8.3%	±0.8%	234	29

The division of the MACs in five charge groups as per Table 11 makes absolute differences in annual leakage rates visible. The difference in leakage rate between systems with 700-750 grams (first group) and systems with 1,100 grams and more (three groups) is statistically significant. Therefore, with some justification it can be

said that large-sized MACs lose more refrigerant per year in absolute terms than smaller systems. This result is graphically shown in Figure 8.



**Figure 8: Different MAC charges show differences in annual leakage rates (grams/year); some differences are statistically significant.**

In relative terms, MACs of all charges are very similar as to leakage rates. The percentages vary just a little, from 7.9 to 9.0 % with no significant differences.

For every truck MAC the percentage leakage rate is the same regardless the refrigerant quantity. That means, and it is proven here that the systems lose refrigerant according to the size of their charges; low-charged MACs emit half the HFC-quantity of high-charged systems. From this it follows that a MAC design that lowers refrigerant charges, can contribute substantially to reduction in HFC-134a emissions. The room for reduction in overall regular emission through charge reduction is estimated at 30% - if every MAC had a charge of only 750 grams.

### V.7 Average annual leakage rates by mileage

The longer the distances that trucks have covered in their use-phase, the more refrigerant has leaked from their MAC system. In fact, every high mileage means long run of the engine and thus increased strain from heat and vibration. A close connection between driven kilometres and absolute amount of refrigerant loss can easily be verified for the sample of this study:

Trucks with mileage of 600,000 km have lost about 300 grams so far, while the loss from trucks with 100,000 km on the odometer amounts to just 80 grams.

This correlation is self-evident, to a certain degree because the mileage of a truck goes in parallel with its age, generally. The influence of mileage on leakage rates independent from age must be determined for a definite time, the mileage per year.

The influence of the kilometres driven per year is shown in Table 12 and Figure 9.

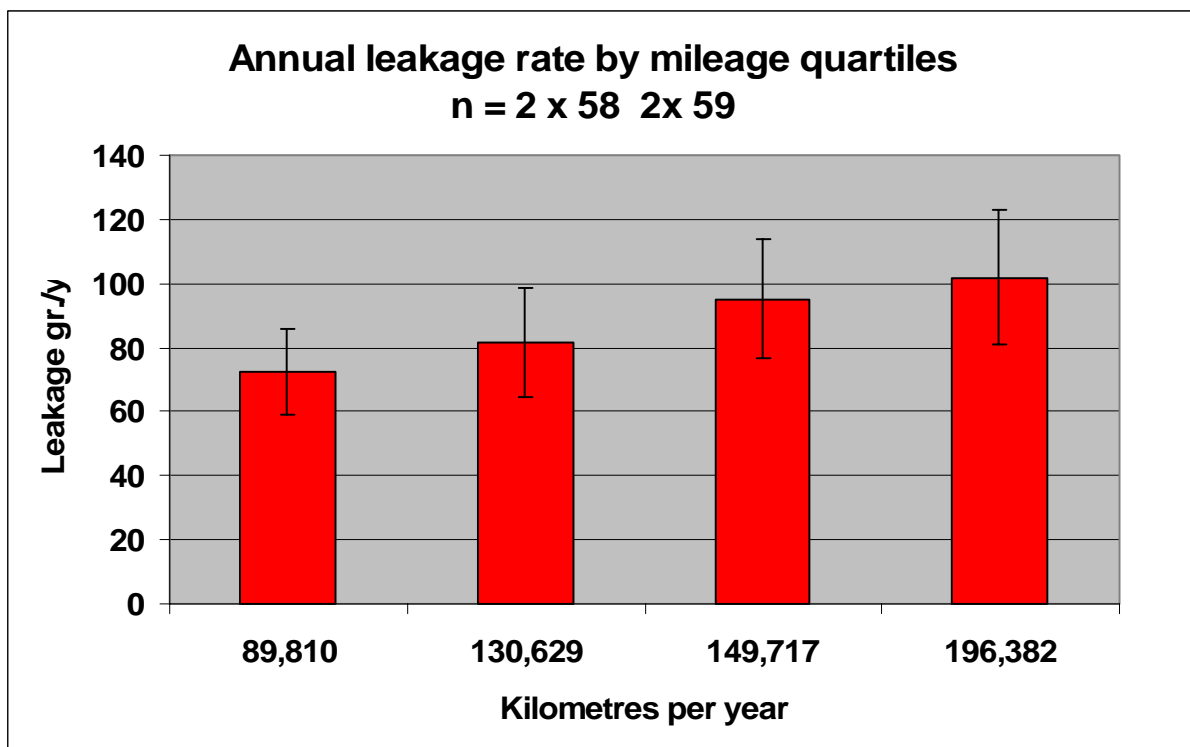
Average mileage per year in the sample is 141,822 kilometres. Dividing the 234 sample trucks into four equal groups (quartiles) according to their mileage per year the first quarter includes 58 trucks with average mileage of 89,810 km/y; the last quarter contains 59 trucks with the double mileage, 196,382 km/y.

**Table 12: Average annual leakage rates by kilometres per year (quartiles)**

<b>Average range</b>	<b>89,810</b>	<b>130,629</b>	<b>149,717</b>	<b>196,382</b>
<i>Number</i>	58	59	58	59
<b>Leakage rate grams/y</b>	<b>72.5</b>	<b>81.4</b>	<b>95.3</b>	<b>101.9</b>
Error band grams	±13.4	±17.1	±18.7	±20.8
<b>Leakage rate percent</b>	<b>7.2</b>	<b>8.2</b>	<b>9.0</b>	<b>8.9</b>
Error band percent	±1.5	±1.8	±1.7	±1.6
<i>Av. Age in months</i>	34	33	28	23
<i>Av. Charge grams</i>	1,072	1,009	1,041	1,105

The average annual leakage rate increases with growing mileage. It is 72.5 grams in the first quarter, and grows to 101.9 grams in the last quarter. However, the differences are statistically not significant. This can also be seen in Figure 9, where the error bars of the first quarter overlap with the error bars of the last quarter.

The four average leakage rates in percent do not differ significantly from each other.



**Figure 9: Slow growth of annual leakage rate with doubling in mileage per year.**

Obviously, the influence of the annual mileage on the leakage rates is small. Vehicles with 50% more mileage than the average do not significantly lose more refrigerant from their MAC than vehicles with 50% mileage below the average.

## V.10 Conclusions

In this study it has been established that the leakage rate of “second generation” MACs of trucks over 16 t GVW in the EU averages 87.8 grams of HFC-134a per annum. Expressed as percentage of the original refrigerant charge this equals 8.3 percent/year.

These values are true as far as the measuring sample represents the reality of the EU wide truck fleet.

The influence of annual mileage on the leakage rate seems to be small, and apparent differences in leakage rates by truck makes are not validated by strict tests of statistical significance. This also applies to indications that relatively new MACs show higher leakage rates than systems over three years in use.

MACs of different charges lose an equal percentage of their refrigerant per year. As the norm fills are widely spread from 700 to over 1,450 grams, smaller charged MACs (700-750 grams) were found to have a significant smaller leakage rate in grams per year than bigger charged systems. This seems to indicate that there is ample room for reduction in HFC-emissions by establishing MAC designs that lower refrigerant charges.

The results of this study need to be compared with the other HFC-134a emissions that occur during the whole lifetime of the air conditioner.

In addition to regular emissions as established in this study, in the use-phase of a truck "irregular" emissions have to be considered. The author of this study estimates "irregular" emissions at roughly 30 grams<sup>21</sup>. Adding “regular” and “irregular” emissions and assuming that the expected lifetime of a truck is ten years, the expected greenhouse gas emission from a mobile air conditioner in the EU is about on average 1.5 tonnes<sup>22</sup> of CO<sub>2</sub> equivalent over the use-phase.

These emissions need to be complemented by HFC-134a emissions before the vehicle was taken into use, the service emissions and the end-of-life emissions, as well as CO<sub>2</sub> emissions due to the increased fuel consumption as a consequence of operating the air conditioner. In conclusion, while “regular” HFC-134a emissions are likely to be the single most important source of greenhouse gas emissions from mobile air conditioners, it is important to estimate the amount of other HFC-134a and CO<sub>2</sub> emissions to understand the full climatic impact of mobile air conditioners.

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<sup>21</sup> The estimation is based on the experience during the measurements that about 50 of overall 300 MACs to be tested had to be ruled out because of previous damage or repair. Exclusion happened either instantly or in the sample correction at latest. 50 units distributed over six model years, comes to 8 or 9 MACs per year, which must be assumed to loose a complete refrigerant charge "irregularly". If one compares these 8 to 9 kg per year (average charge is 1,057 grams) with the regular leakage of 300 MACs, namely 26 kg (300 x 87.8 grams), irregular leakage amounts to additional 35% if regular leakage of 87.8 grams is set 100%. Then, 35% are equal to ~30 grams.

<sup>22</sup> (0.088 kg + 0.030 kg) · 10 · 1,300 = 1,534 kg. (The GWP of HFC134a is 1,300.)

## **Annex I Measurement Protocol**

### **Measurement Protocol for the Establishment of Leakage Rates of Mobile Air Conditioners: How to operate recovery stations to determine MAC refrigerant charges**

#### **I. Introduction**

All types of commercially available recovery stations can be used to measure the actual refrigerant level of a MAC, at least in principle.

Simple manually operated devices are equivalent to automatic machines for this purpose. With respect to filling, modern stations with built-in scales displaying changes in the tank's weight digitally may be superior to units with simple transparent cylinders for measuring by sight. However, this does not apply to recovery.

This is why it cannot be taken for granted that the increment in the tank's weight exactly equals to the refrigerant quantity sucked into the recovery station. Mass shifts (liquid/gaseous) in the station's piping, especially in the condenser, cannot be excluded. Thus, it is possible that the refrigerant does not completely reach the reservoir tank, or that refrigerant from the preceding operation enters the tank, additionally.

Removal of insufficient accuracy is the essential feature of the Measurement Protocol used in the truck MAC survey. It consists of using external scales with high resolution to put the whole recovery station onto a load platform before and after each suction operation. By using an external scale the refrigerant distribution within the recovery station can be ignored.

It is also important not to forget that some oil could be entrained by the refrigerant during the suction extraction. This oil may be collected in the station's oil-separator. In order to measure the amount of refrigerant recovered accurately, this oil has to be drained off after every recovery cycle.

Below, this method is described in all its individual stages as accurately as possible. The reason for that detailed protocol is not only to explain the confidence level of the measurement results but also to present uniform and clear rules for future measurements wherever they might be carried out.

It goes without saying that the person performing such measurements must be a well-trained and experienced technician.

## II. The measurement equipment used

All the 271 measurements of the EC truck MAC study were carried out with four similar relatively simple recovery stations. Often they were used simultaneously, and the performance of every station was the same. The stations were:

1. RHS 850 WAECO – A'GRAMKOW 134a (two units – 133 measurements)
2. RHS 650 WAECO – A'GRAMKOW 134a (one unit – 71 measurements)
3. RHS 640 WAECO – A'GRAMKOW 134a (one unit – 67 measurements)

Although RHS 640 and RHS 650 are "light" versions of RHS 850, there are no differences from each other in essential functions.

### II.1 Specifications of the recovery stations

All types are equipped with internal refrigerant cylinders of 4 kg capacity. The current refrigerant level can be read off by sight glass.

At every station two service hoses are connected, the blue one (72") for the low pressure and the red one (72") for the high pressure, each with standard length of 180 cm. On the instrument panel two shut-off valves can be operated: the low-pressure valve and the high-pressure valve. Five different on/off switches can be used, apart from the main switch there is one for "Recovery", "Recycling", "Evacuation", "Recharging". Three pressure gauges are displayed on the instrument board of the RHS 650: Vacuum gauge, high-pressure gauge, and low-pressure gauge. At all stations special valve-controlled oil-injectors are fitted to the outlet of the high-pressure hose (by means of a special adapter) to add refrigerant oil to the hose while it is in a vacuum.

The weight of the empty RHS 850 is 90 kg; the net weight of both RHS 650 and RHS 640 is 70 kg. The voltage is 220V and 50 Hz, allowing the use of usual cables and plugs.

### II.2 Specification of the scales

The surface plate of the load platform is made of steel for a maximum load-bearing capacity of 120 kg. Its dimensions are 800 x 600 mm. The load cell (the analogue to digital converter of load to electrical signals) facilitates a weight resolution of 10 grams, and the weight can be read off a LCD display. The voltage for the scales is 220 V - 50 Hz. The scale is a special making up of the German company "Waagen Krug" for the purpose of the study. Commercially available scales of the same resolution and load-bearing capacity cost about 4.000 Euro.



**Figure 10: Service station Waeco RHS 650 on the scale after the recovery operation.**

The picture was taken during measurements 28 October 2006 in Laufach, Germany (Bavaria).

### **III. Fourteen individual steps of the measurement cycle**

The first measurement requirement is a sufficiently long resting time of the MAC to be tested. The compressor should not run 24 hours before the recovery begins otherwise the refrigerant extraction is seriously impeded as more refrigerant is held dissolved in the lubricating oil. Thus, it is advisable to work in pools that have a sufficiently large number of trucks available. Of course, the vehicles shall fit the selected mix of makes, models, and age. That should be clarified before measuring.

#### **III. 1. Weighing the recovery station**

The recovery station, its hoses and oil separator must be empty before weighing. All these are weighed as a whole on a dedicated load platform with resolution of 10 grams at least. The displayed weight of the empty system needs to be written down (e.g. 71.88 kg).

#### **III. 2. Visual check of the MAC**

The recovery station is brought to the selected vehicle. The technician should first make a visual control to establish whether the AC shows a mechanical damage or any indications of previous repair, which the pool manager or the driver have forgotten about. If so, this MAC should not be tested.



### **III. 3. Connecting hoses to the MAC**

The protection caps are removed from the MAC service ports and the quick fitting pipe union of the [blue] low-pressure hose is attached to the low-pressure service port while the pipe union of the [red] high-pressure hose is joined to the high-pressure service port of the MAC. [To avoid any confusion the low-pressure service port is smaller than the high-pressure port.] Measurement is possible even if only the high-pressure service port can be connected.

### **III. 4. MAC pressure check**

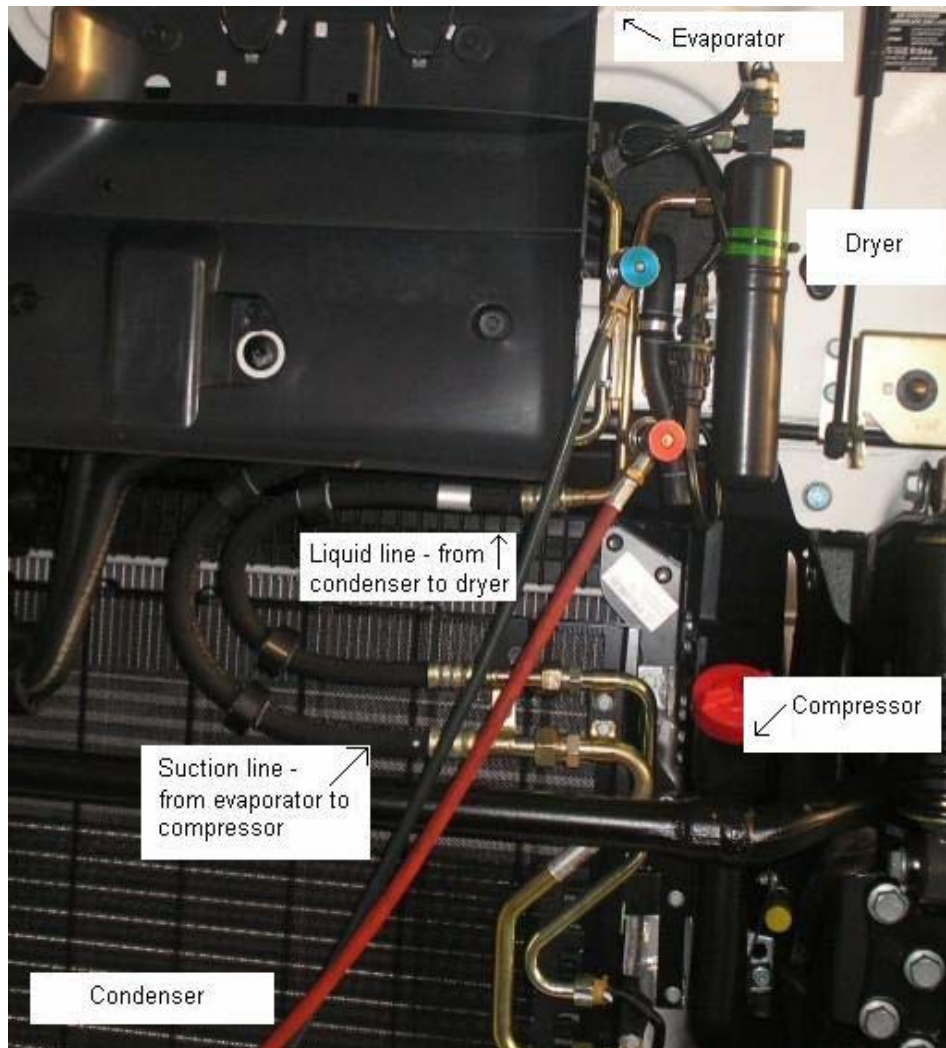
The valves of the service connections are opened by manually turning the cock of the unions, and immediately the MAC's low pressure (suction pressure) and high pressure (liquefying pressure) readings are displayed on the station's pressure gauges provided. (If only one service port is joined, only one gauge works, of course). Both gauge dial values (in the case of two ports) should be alike as the different pressures have evened out inside switched-off MAC systems, and the values should range between 4 and 6 bars (absolute) corresponding to ambient temperature of from 10°C to 20°C as long as there is a minimum (at least about 50 grams) of refrigerant inside the system. Thus, the pressure gauges provide the next indication of the system's condition. If no pressure at all is displayed the MAC is obviously empty and a hidden mechanical leak is very likely. Anyway, the service station would not run then. Such vehicles are ruled out from further measuring, too.

### **III. 5. Switching on recovery**

By turning the recovery station on "recovery" the compressor starts suctioning and draws the refrigerant in as long as its own suction pressure is lower than the pressure inside the MAC. The pre-set working low-pressure of all the stations applied in the course of the measurements was 0.6 bars absolute. The refrigerant from both the high-pressure side and the low-pressure side of the MAC passes over a single main line leading inside the recovery station, flowing eventually into a reservoir tank (bottle, cylinder). The oil-separator near to the station's inlet holds back any entrained refrigerant oil.

### **III. 6. Running the suction operation**

The recovery station's compressor automatically switches off at 0.6 bars absolute (equalling – 0.4 bar relative to normal pressure) and switches on again when the pressure has increased by approx. 0.8 bar caused by after-evaporating refrigerant which may have been dissolved in oil, or had not immediately been withdrawn from the lower parts of the refrigerant circuit. The pre-set value to cause renewed recovery is 1.3 bars absolute at all the stations used for the EC truck measurements. The extraction process starts again on any renewed rise in pressure in the AC system above 1.3 bars absolute and continues recovering. The entire recovery process is not finished before a rise in pressure above 0.6 bar no longer occurs over five minutes. Thus, the entire extraction lasts at least 20 minutes; in case of ambient temperature below 15°C five minutes more should be given.



**Figure 11 Actros MAC on control test 7 Nov 2006. Look under the front hatch. Picture centre shows the liquid up line from condenser to dryer (top right) is a rubber hose like the suction down line from evaporator (top - non visible) to compressor (inside bottom - non visible). Flexible piping is demanded by the cabin which is not rigidly fixed to chassis.**

**Next to the dryer bottle the two service ports are connected to the hoses of the recovery station.**

Comment: As the suction operation of the recovery station runs automatically, the technician can use the time either to start a second measuring cycle at another car (on condition a second station is available) or he can collect and note down the basic and possibly additional data on the vehicle as requested by the questionnaire. It suggests itself to use a special reporting form to fill the data in to prevent any data from being forgotten. (The data reporting form used for the survey is presented at the end of this chapter).

### III. 7. Detaching the hoses

After the extraction the hoses must be detached from the MAC's service ports, whose valves get closed by that, locking up the MAC system at an inside pressure of 0.6 bar absolute. The recovery station with its empty and also closed hoses is brought back to the weighing platform.

### III. 8. Draining off the oil

To avoid falsified measuring results, before weighing the recovery station which now contains the extracted refrigerant, the oil separator must be drained off. Usually the

little amount of oil, if any at all, can be captured manually in a measuring cup which allows determining the quantity to give back the same volume of (fresh) oil to the MAC, later. Of course, the automatic way of draining off the oil is equally good.

### **III. 9. Second weighing**

The recovery station is now weighed a second time on the load platform, and the new weight must be noted down. It depends on the setting, whether the total weight of the recovery station or only the increment in weight since first weighing is displayed by the dial. Both versions are basically equivalent. But when using more than one recovery station, it is not recommended to zero the scales to avoid mixing up the one with the other recovery station's weight. At any rate, the weight's difference against the first weighing is the objective of the whole exercise.

### **III. 10. Back to the vehicle to recharge the MAC**

To refill the MAC system to the norm charge<sup>23</sup> the technician needs to move the recovery station a second time to the vehicle. This time only one hose needs to be attached. The service port in question is generally on the high-pressure side and so it is the high-pressure hose to be coupled up for filling. The quick-fitting pipe union of the hose should be attached but not yet opened, before the desired refrigerant quantity is not released into the hose.

### **III. 11. Adding the oil**

Before releasing the refrigerant norm charge out of the reservoir tank, fresh oil of the same amount as extracted and captured before, must be given into the filling hose, automatically or manually. One elegant way of manual addition is a short (up to 3 minutes lasting) evacuation of the filling hose which is still locked at both of its ends. The then extremely low pressure inside the hose allows filling in the oil easily with the help of an oil injector as its is used to transfer oil into a vacuum.

Comment: This is the only case the vacuum pump of the station is needed, quite differently from the usual practice when servicing a MAC including mechanical opening the MAC, leak detection and possible repair. For the limited purpose of just recovery and recharging a MAC, the removal of non-condensable gases by running the evacuation process is not necessary.

### **III. 12. Recharging refrigerant**

Modern recovery/recharging stations allow automatic adjustment of the required refrigerant quantity to flow from the station's liquid reservoir tank into the MAC

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<sup>23</sup> Of course, to top-up the MAC to the norm charge is no necessary step of a measurement cycle. But to offer that service to the truck operator is a reward to increase his willingness to hand over the cars for leakage test. Mostly, the norm fill can be read off from a label at the vehicle itself or, if there is no label, must be taken from an appropriate manual. Alternatively, the workshop that usually services the trucks has to be asked.

system. This is done by entering the norm fill with the help of a keyboard on the station's instrument panel. By switching on "recharging" the charging valve gets opened and the defined quantity leaves the tank to flow into the filling hose and through it into the MAC as soon as its service connection is opened.

Using simpler stations the required refrigerant quantity needs to be measured by eye. The technical difference to automatic machines is that the measuring is only possible together with recharging, not before that. The valve of the charging hose at the station must be opened as well as the service connection of the MAC. Then the fill level of the transparent reservoir tank falls as the tank contents flow out, so the amount of refrigerant discharged can be visually checked during charging by reading off the measuring lines encompassing the transparent tank. The refrigerant flow must be stopped manually by closing the charging valve when the refrigerant level has decreased to the envisaged marking.

### **III. 13. Detaching and closing the hose**

After recharging, the quick-fitting pipe union of the filling hose must be detached and by doing so the hose's end as well as the service connection of the MAC gets closed. The hose, which is not empty but still filled with refrigerant, can be taken off the vehicle, and the protection caps should be fitted over the service ports again.

### **III. 14. Emptying the hose**

Both in the automatic and the manual way of recharging the refrigerant flow is driven by the difference in pressure of initially 6 bars between reservoir tank and MAC system. The pressure in the MAC rises as the charging operation proceeds, which stops the hose and pressure-gauge fittings from being entirely emptied of refrigerant. Therefore the detached and at its end well-closed hose must be emptied by suction by turning on "recovery", i.e. the compressor, again. This is a very important step; otherwise the next recovery cycle would be seriously distorted. Up to 50 grams of refrigerant may still remain in the hose depending on its length.

## **IV. Further data to record in the context of a measurement**

The technician performs the measurements of the MAC's charge mainly by operating the recovery station. The final destination of the measurements is the establishment of a leakage rate and a better understanding of its influencing factors like age of the MAC, make and model of the truck, mileage, and that like but also of the circumstances of the measurements themselves.

Apart from the recovery of the MAC's refrigerant charge, following basic data must be reported at any rate. They are broken down into data on the vehicles and data on the measurement itself. As a minimum the following data must be gathered.

### IV.1 Basic data on vehicle

1. Vehicle Identification Number (VIN)
2. Date of First Registration of the vehicle
3. Truck manufacturer
4. Vehicle type and model
5. Kilometres on odometer
6. Norm charge as labelled at the vehicle  
(as far as it can be found out at the measurement place itself)

### IV.2 Basic data on measurement

1. Place of measurement
2. Serial number of measurement
3. Date of measurement
4. Time of start and end of measurement
5. Ambient temperature during measurement
6. Recovered refrigerant in grams

### IV.3 Data Reporting Form

The Data Reporting Form as used at the truck measurements from July to November 2006 is presented overleaf.

**DATA REPORTING FORM FOR RECOVERY OF REFRIGERANT FROM TRUCK MACs**

**Background data**

- 1. Name of truck operator: .....
- 2. Date of measurement: ..... / ..... / 2006
- 3. Serial number of measurement: .....

**Measurement data**

- 4. Model of recovery system\*:  RHS 640 /  RHS 650 /  RHS 850
- 5. Ambient temperature during measurement: .....°C
- 6. Time at start and end of measurement: .....
- 7. How much refrigerant was recovered? ..... grams

**Vehicle data**

**Information collected at the vehicle**

- 8. Registration Number of the vehicle .....
- 9. Manufacturer and model of vehicle: .....
- 10. Engine power (hp) and Gross Vehicle Weight: .....
- 11. Vehicle Identification Number (VIN) (17 characters): .....
- 12. Cubic capacity (piston displacement): ..... cm<sup>3</sup>
- 13. Kilometres on odometer: ..... km
- 14. Preceding repair or refill of the MAC?\*                      Yes                       No                       Unclear

**\* Please tick one option!**

**Information collected from records if not available at the vehicle**

- 15. First registration of vehicle (day/month/year): ..... / ..... / .....
- 16. Prescribed nominal charge of HFC-134a (incl. tolerance band): ..... grams
- 17. Additional observations: .....  
.....
- 18. Signature of technician: .....

## Annex II Participating Truck Operators

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