F-GASES IN REFRIGERATED TRANSPORT

T. MICHINEAU, G. CAVALIER, E. DEVIN

Cemafroid, 5 avenue des Prés, CS 20 029

Fresnes, 94 266, France

thomas.michineau@cemafroid.fr

ABSTRACT

Considering that transport will be included in the F-gas revision for all equipment over 2kg of HFC refrigerant and the environmental impact of refrigerated transport is more and more considered in Europe with Eco-design or, Carbon foot print, the authors have evaluated the quantity of F-gases loaded in refrigerated transport vehicles in France.

Even if the current market is dominated by one technology based on vapour-compression systems using R-404A as refrigerant, the article shows that some changes are occurring concerning refrigerant choice. This article highlights the strong influence of Regulation either at a National or European level on refrigerant choice. Refrigeration unit manufacturers are developing alternatives to HFC, those alternatives will be compared in terms of environmental impact, efficiency, and availability on the market.

In conclusion the author will evaluate the potential impact of a change of refrigerant in transport in Europe.

1. INTRODUCTION

Till now, refrigerated transport was not directly concerned by the European F-gas regulation, neither by the energy efficiency classification. Within the framework of Kyoto and Montreal protocols, CFC and then HCFC's were abandoned as working fluids in the refrigeration units and as blowing agents in the insulation foams. In the early 2000, HFC were generalized for transport refrigeration units and hydrocarbons taken as blowing agents. For more than ten years now, no major changes occurred concerning F-gas applications in this sector.

The F-gas revision in process will introduce major changes for refrigerated transport mainly by including it within the scope of the regulation. At the same time, the eco design directive and the carbon footprint analysis introduce new approaches of the equipment. Transport refrigeration units are mainly using vapour compression systems with HFCs as refrigerant. The R-404a is the most common refrigerant used in refrigerated transport with R134a. The phase down of HFCs in the next years will directly impact refrigerated transport equipment technology. It is now sure that transport refrigeration units will change tremendously during the next years.

It appears then really interesting to analyze what is the real situation of the transport refrigerated fleet with regard to F-Gases, what are the available solutions on the market or what could be the solutions to test in the near future.

This paper presents and deeply analyses the French refrigerated transport fleet and evaluates the F-gas load and the need for maintenance in the future. It presents the existing alternatives to HFC with high GWP for refrigerated transport applications and the possible research directions for compression systems or other technologies.

2. F-GASES IN REFRIGERATED TRANSPORT FLEET

2.1. Refrigerated transport fleet

Refrigerated transport met a continuous growth in the world since the 50's. The last RTOC report [1] evaluates to 4 million the terrestrial fleet of refrigerated transport equipment in service in the world in 2010. In addition, the world fleet of marine reefer containers is evaluated to 850 000 units in 2013. Nevertheless the situation is quite different from one continent to another and from one country to its neighbors.

The overall refrigerated terrestrial transport equipment in the European Union is estimated by Cemafroid to some 1,1 Million equipment in 2012 in the 27 countries. This evaluation is based on UNECE, IIR, EU and expert's figures and their evolution in function of time. If accurate data are available in Spain, France or Italy, only evaluations are available in most of the other countries.

2.2. Available data

In 1998, the French government decided to centralize the ATP certificates management system spread over more than 100 local authorities and asked the Cemafroid to build a technical model. In 2002 was developed the first database and computing systems DATAFRIG®. It was improved in 2005 integrating most of the existing data before 2002. The last version, far more detailed was published in 2009 and regularly updated until now. Some 600 users are connected to DATAFRIG. More than 300 000 equipment are available in the database, roughly half of them are still in operation. The detailed analysis was done with this data. The figures are validated by a four step process : the manufacturer first enter and validate its data in DATAFRIG, DATAFRIG then make an automatic check of the figures such as refrigeration capacities or dimensioning, then a first operator checks the demand which is finally validated by a second expert. This process guarantees a very good level of control and a high quality of the information in the DATAFRIG database.

We analyzed on one hand the fleet of refrigerated transport equipment in service at the end of the year and on the other hand the annual production of new equipment.

2.3. Refrigerated transport equipment

In France some 52 % of these equipment are light vehicles (Vans) of less than 3,5 t. Trucks of more than 3,5 t represents 22 % and trailers and semi-trailers 24 %. The other pieces of equipment such as containers, mobile boxes and rail coaches represent 1% almost of the total fleet. Some 24 % of this equipment is multi-compartments but multi-temperatures represent more than 50 % for trucks and 38 % for semi-trailers.

In 2012 the total fleet of in-service equipment may be spread as:

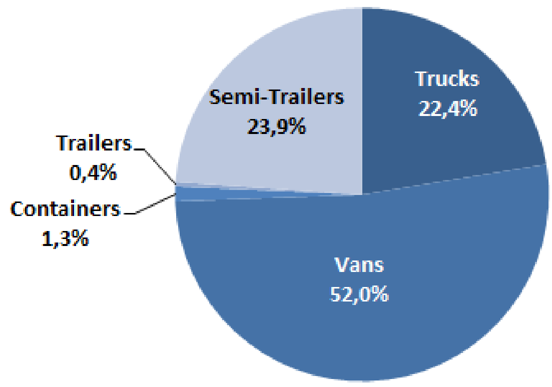

Figure 1. French segmentation based on categories of vehicles (in service equipment in 2012)

Table 1. ATP French Refrigerated vehicles fleet in 2012

Type of vehicle	Number of in-service equipment in 2012
Trucks	27 087
Vans	62 881
Containers	1 537
Trailers	470
Semi-trailers	28 908
Total	120 883

2.4. Refrigeration units for transport

The majority of equipment is refrigerated by vapour-compression systems. Among them, only 4 % are equipped with eutectic devices composed of plates or tubes and 96 % with air blown evaporators. Very few equipment are refrigerated by liquid cryogenic systems, direct or indirect. Solid cryogenic systems are dedicated to small containers and very few trucks.

In France in 2012, 39 % of the fleet is equipped with motor driven units and some 60 % with autonomous units powered, most of the time, by diesel engines.

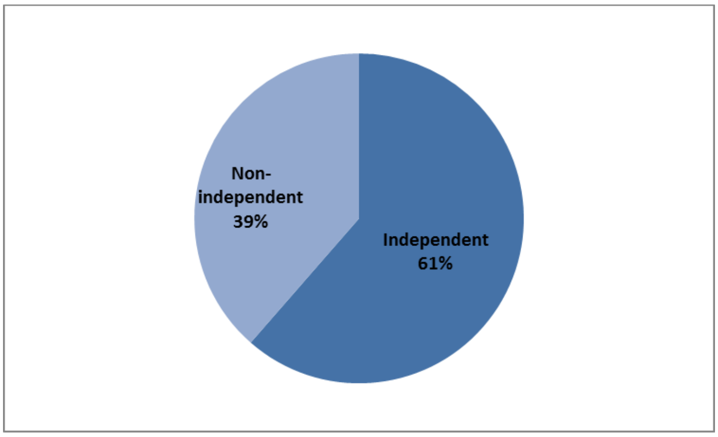

Figure 2. Ratio of independent unit/non-independent units in service in 2012 in France

The refrigeration capacity varies from some hundred watts per unit up to some tens thousands for the bigger units. If most of the unit are able to operate at 0 °C/+30 °C and -20 °C/+30 °C with R-404A, the smallest ones are only able to operate at 0 °C/+30 °C, they generally use R-134a.

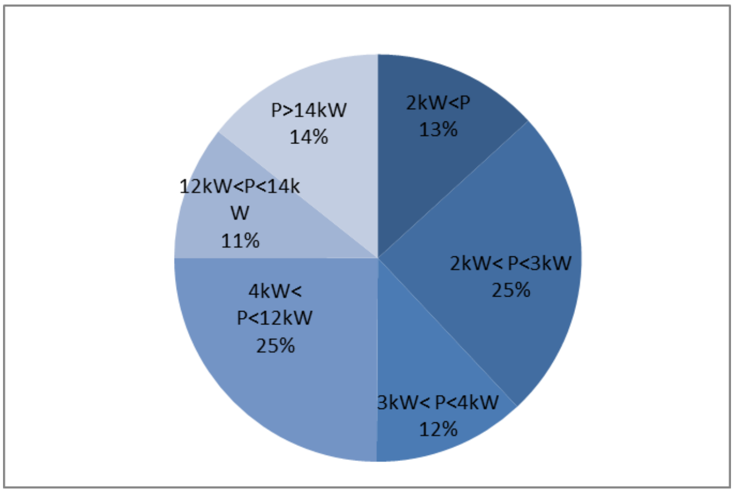

Figure 3. In-service equipment segmentation per nominal capacity at 0°C

3. F-GAS IN TRANSPORT REFRIGERATION UNITS

2.5. Refrigerants used

Since their apparition in the late 30's in America and the 40's in Europe, transport refrigeration units are mainly using vapour-compression systems. After CFCs and HCFCs, manufacturers turned to HFCs as refrigerant in the early 2000s. The R-404A is presently the most common refrigerant used in refrigerated transport with R-134a. 85% of refrigerated transport vehicles are using R-404A

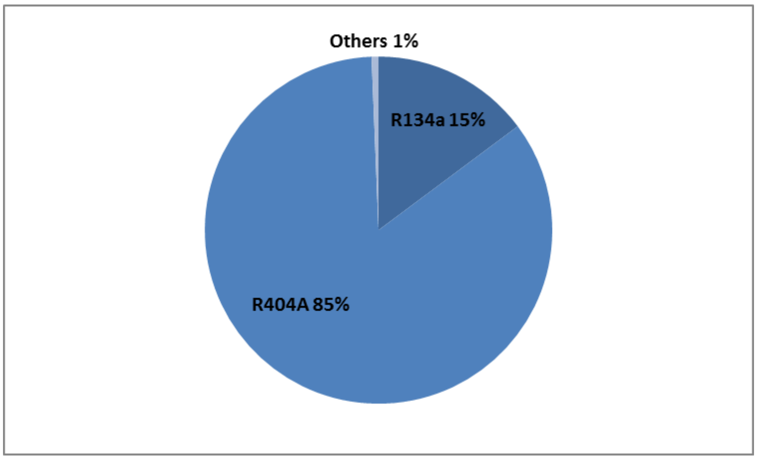

Figure 4. Type of refrigerants used in in-service equipment in 2012

It appears clearly that R-404A occupies a very large part of the market with more than 95% of the total load of the new units commercialized in 2010 and 2011 that have received an ATP certificate in France.

The second F-gas commonly used, the R-134a refrigerant represents only 4% of the total load for the same period and the third one the R-410a refrigerant less than 1%. These figures may vary a little bit from one country to another in Europe with the specificities of the national markets, but the main tendencies are common.

Table 2. Refrigerant load per refrigerant over the past 3 years

refrigerants type	2010		2011		2012	
	Mass (Kg)	%	Mass (Kg)	%	Mass (Kg)	%
R404A	47543,31	95,7%	39761,18	95,4%	37261,36	95,9%
R134a	1894,754	3,8%	1771,105	4,2%	1341,3	3,5%
R410A	255,2	0,5%	158,9	0,4%	239,5	0,6%
Others	0	0,0%		0,0%	5	0,0%
Total	**49693,264**	**100,0%**	**41691,185**	**100,0%**	**38847,16**	**100,0%**

The proportion of units loaded with R-404A is lower because the units using R-134a are the smallest ones. Nevertheless, the end of R-404A in refrigeration in a near future will tremendously impact transport refrigeration.

On the market, refrigerant units represent a specific sector with some 3 to 4 % of the fleet. If they used also vapour-compression cycles, their evaporation temperature is quite lower. Neither R-134a nor R-404A may be operated, they generally use R-507.

2.6. Refrigerant loads

The refrigerant loads are quite different for independent and motor driven refrigeration units. If for non-independent units, refrigerant load is about 1,66 kg it is about 6,85 kg for independent unit.

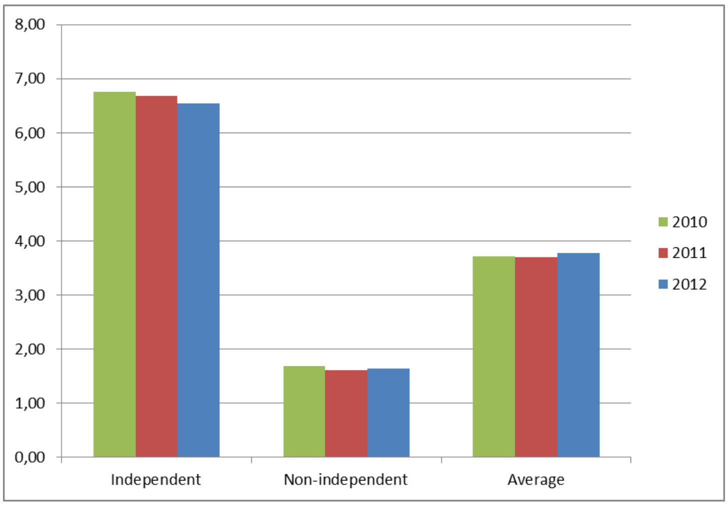

Figure 5. Refrigerant load per type of vehicles over the past 3 years

This analyses also reveal that the current average F-Gas load in transport refrigeration units is of 3,86 kg/unit but this load depends on the technology of the unit, its refrigeration capacity and installation in the body.

Table 3. Refrigerant load for independent or motor driven equipment over the past 3 years

	2010		2011		2012	
	average (kg)	total load (kg)	average (kg)	total load (kg)	average (kg)	total load (kg)
independent equipment	6,75	36114,17	6,76	30970,59	6,55	29303,27
motor driven equipment	1,65	13579,1	1,69	10720,595	1,65	9543,89

For the total European fleet, we can extrapolate the total load using the total number of equipment and the average load. This extrapolation gives for the 1,1 million European refrigerated transport equipment, 4 246 t of F-Gases among which more than 4 000 t of R-404A.

4. ALTERNATIVES

In this situation, it is absolutely necessary to find in the next years solutions to replace R-404A in transport refrigeration systems. Manufacturers have already proposed alternatives; they are experimenting new solutions and preparing new innovations. Cemafroid has recently performed a study on alternatives to high-GWP HFCs in refrigeration and air-conditioning applications [6]. The paragraphs hereafter are summarizing possible alternatives to R-404A vapour-compression systems per applications.

4.1. Low GWP alternatives in vapour-compression systems

The first alternative to transport refrigeration systems using vapour-compression systems with R-404A consists of new refrigerants with low GWP using the same technology of vapour compression.

Refrigerating unit manufacturer and refrigerant producer are investigating low GWP alternatives such as natural fluids with CO_2, HFO, hydrocarbons, or with new HFCs and HFC's blends.

- HFCs

The easiest solution to replace R-404A would be to drop in another fluid with a lower Global Warning Potential. The first candidates are HFC's existing or new.

Some manufacturers have already chosen the R-410A for their entire production (GWP 1725) taking into account that future F-gas regulation will probably introduce a limitation of the GWP at 2500. The place of R134a may even increase. Nevertheless, both of them still have an important impact in term of greenhouse gas effect.

Among the "low GWP" HFC available, R-407A refrigerant (GWP 1770) or R-407C have been mentioned has a possible "drop in" solution for transition. According to major manufacturers, the replacement of R-410A directly by the R-407A implies major technical modifications of the refrigerating units (especially the regulation system) and strongly reduces the refrigeration capacity.

- HFOs

In order to anticipate the regulation, chemical company has developed especially for the car air conditioning market, new refrigerants based on unsaturated HFCs. These new refrigerants have the molecular properties to limit the lifetime of components which have a greenhouse gas impact. This new refrigerants are under test by some manufacturers. Till now, no real prototype has been issued. They will require at least a strong reengineering of the units.

HFO refrigerants have been evaluated by some manufacturers [7]. Even if the performances can be reached through the evolution of the units, the drop-in is not directly possible.

- Hydrocarbons

Developments are going on for natural fluids in transport refrigeration units. Hydrocarbons are also used in blend of HFC in order to limit the GWP. The problem of their safety classification and availability of standards is the main obstacle of this alternative.

Indeed, hydrocarbons have been proposed but taking into account the loads in transport refrigeration units and the conditions of use, safety issues are then of high importance and make it too difficult and dangerous. They will certainly not represent an alternative in transport. Nevertheless the use for maintenance of counterfeits refrigerants composed of hydrocarbons blend is increasing through internet sales increasing the danger for this equipment.

- Natural refrigerant - CO_2

CO_2 is the main natural fluid valuable for transport refrigeration units. It has already been tested for years by some manufacturers especially for marine containers. The traditional units needed large evolution to allow a safe and efficient use of CO_2 in vapour-compression cycles while the conditions of use and the temperatures required are very large.

The first units are commercialized for some months now on reefer containers for marine refrigerated transport. Strenghtened by its commercial success, Carrier [8] has also officially announced field tests on terrestrial transport units and plans to provide a full range of CO_2 transport refrigeration units by 2025.

CO_2 systems are not yet available for road transport application, but since 2012 for marine reefer containers. This is probably one of the most credible natural refrigerant alternatives for refrigerated transport equipment. Semi-trailers using CO_2 units derivated from CO_2 marine reefers units are on test in UK.

4.2. Alternatives technologies to vapour-compression systems

One solution would consist in replacing the traditional vapour-compression system to avoid the use of F-Gases from transport refrigeration units. If it is technically possible, is it possible at an acceptable price.

- Cryogenic systems

It is the solution proposed by some manufacturers with liquid cryogenic systems. These solutions appeared on the market in the 70's. They didn't met the expected success. They were updated during the last decade. Direct or indirect solutions using N_2 or CO_2 are now available again. They offer interesting alternatives in some applications. Their high refrigeration capacity, their energy consumption proportional to the needs, their low level of noise are strong advantages but the absence of liquid gas distribution network, their cost of exploitation are also strong disadvantages. If these units have really a place on the market especially for city distribution they will certainly not be the sole solution and will not replace all the vapour-compression systems.

- Sorption systems

Other trials have been conducted on adsorption and absorption units but this technology is not operational except for small equipment's such as small containers of less than 2 m3. Adsorption systems with ammonia and salt or water and zeolites have been qualified during the last years [9]. They require research investments to be used broadly on the market in the next years for example for vans or bigger units. These systems, even if they generally offer lower COPs, can use waste energy, thus reducing the environmental impact of the technology [9].

- Air systems

In the research fields it is possible to adapt to refrigerated transports solutions developed in other sectors such as storage. It is possible to adapt air systems to transport [10].

- Magnetic refrigeration

If some prototypes of magnetic refrigeration machines are on the hedge to be produced in industrialized plants [11], their first application will certainly not be in refrigerated transport. Nevertheless they may be a long term solution for some applications.

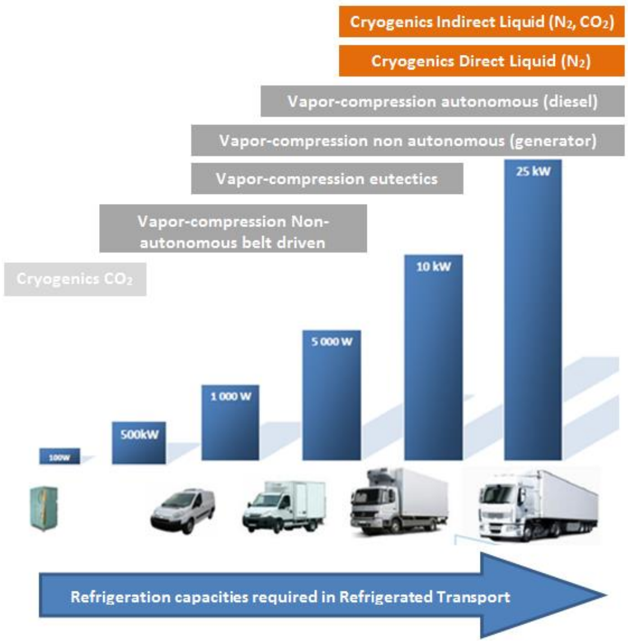

Figure 6. Refrigerant capacity required in Refrigerated Transport

4.3. Alternatives for Eutectics

In the case of eutectics, the replacement of R-507 seems a little bit more complicated until now. The total load of R-507 was 10000 Kg in 2012. It is certainly a field of research to propose viable alternatives at a reasonable price.

The table here below summarizes the alternatives discussed in the present article and gives to reader a ranking overview of alternatives:

- A: Available on the market
- T : on field test and development by manufacturers
- S : on study at laboratory
- R : Research and development required before tests
- NS : Not suitable because of risk management
- NA : Not applicable because of performances
- ? to be assessed

Table 4. Possible alternatives to R-404A vapour-compression systems per applications

	Vapor-compression systems					Alternatives Technologies			
Applications	HFC	HFO	CO_2	HC	NH_3	Cryo	magnetic	sorption	Air

Small containers	A	R	R	NS	NS	A	S	A	NA
Vans (Motor driven units)	A	S	S	NS	NS	A	S	R	NA
Trucks and trailers (Independent units)	A	S	T	NS	NS	A	NA	S	S
Trucks (Eutectics)	?	NA	S	NS	NS	A	NA	S	S
Marine reefer containers (electric power)	A	S	A	NS	NS	A	NA	T	S

5. CONCLUSION

With nearly 100% of refrigeration units using HFCs refrigerants with high GWP and more than 95% of the load based on R-404A, refrigerated transport is certainly the refrigeration sector the most impacted by R-404A phase out in the frame of European F-Gas regulation revision in 2014.

Alternative solutions have to be developed and implemented before 2020. New long term durable solutions are absolutely necessary either with new technologies as alternatives to vapour-compression systems or with new fluids in the classical vapour-compression systems. Their availability, their performance and their time to market are different from one to another.

Among the new solutions, CO_2 is a possible long term alternative in the coming 5 to 10 years, new HFCs and blends of HFCs may be a transitional solution for short term, while HFOs are still a possibility. Hydrocarbons are certainly too flammable.

Concerning the alternatives technologies to vapor compression systems, cryogenics may be a niche solution for specific application but never “The only solution”. Absorption should offer an alternative for small capacities, air-system could offer long term solution. For most of them, development is still required.

No doubt that transport refrigeration units landscape will strongly change during the next 20 years, it is a marvelous challenge for all the sector and a source of innovation.

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