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# F-GAS 2017 REVOLUTION IN REFRIGERATED TRANSPORT

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## Introduction

More than 1.3 billion tons of food are lost every year in the world contributing to the increase greenhouse effect. Two thirds of these losses occur before arriving to the consumer in the professional supply chain. Only 400 Mt that is to say 7% of food are refrigerated every year, while 1.8 Billion tons should be that is to say 30% of the world food production. The lack of refrigeration is clearly one of the causes of these losses. Saving food will be one of the solutions to feed the earth in the next 40 years, reducing hunger and malnutrition in the world.

Refrigerated transport is a key element of the cold chain and, if it is well used in developed countries with an average of one piece of refrigerated transport equipment for 450 inhabitants, it is still very poor in developing countries with ten times less equipment. The Chinese fleet for example is smaller than the French one in 2016 while the Chinese population is twenty times higher than the French one. Nevertheless the refrigeration fleet in China has been multiplied by four during the last ten years! Other countries in the world meet the same growth of refrigerated transport fleet. Refrigerated transport is facing and will face a tremendous growth in the world during the coming years.

But this growth is directly affected by the recent evolutions in F-gases regulations in Europe and the Kigali amendment to the protocol of Montreal which imply a phase down and restrictions in the use of HFC. European F-Gas in 2015 and more recently the Kigali amendment to Montreal protocol lead to a revolution in refrigerated transport equipment and more over in refrigerated transport refrigeration units. Refrigerated transport is the kingdom of vapour compression systems with blown evaporators for more than 95 % or refrigerated plates or tubes for the others 5 %. Most of them are using HFC's among which the condemned R404A which plays a major role with more than 95 % of the load in mass in the French fleet for example.

In this revolutionary context, transport refrigeration unit manufacturers are working for some years on short term, medium term and long term alternatives, and, like in all revolutions, new players try to take the opportunity of these major changes to enter the market and get a place with new products.

## The Present Situation in Refrigerated Transport

High GWP HFC refrigerated kingdom is condemned. In 2013, we announced the coming changes in transport refrigeration units, in 2015, we overviewed the possible solutions at short, medium or long term, and in 2017, we can describe the recent important changes and the next coming ones in refrigeration units and insulated bodies. The strong increase of R404A price in Europe and announce from one of the major chemical company to stop distribution of this refrigerant will contribute to accelerate this revolution and will probably accelerate the real ban of HFC.

### Transport Refrigeration Units for Terrestrial Transport

If most of the f-gas charge of terrestrial refrigeration transport unit of the fleet is still composed of R404A, very few pieces of refrigerated transport equipment are now sold with this gas in developed countries and no more units are developed with it. The R404A load in transport refrigerated units represented in Europe some 3 500 t in 2015.

The main road transport refrigeration unit manufacturers have chosen R452A for R404A replacement at very short term because of its drop-in capability and its same thermodynamic characteristics. Most of the existing units of the market have been recertified in the frame of ATP with the new fluid even if long-term properties of R452a are not really known. If the performances are comparable they are not always the same and a slight reduction of the refrigeration capacity may occur due to the major difference with the pure R404a refrigerant : R452a is a blend with a non-negligible glide of temperature. The same situation is met with the R442A chosen by some manufacturers. R452A is a blend of HFCs and HFO, which is also an HFC and its compatibility with existing oil had been demonstrated. It is composed of R-1234yf (2,3,3,3-Tetrafluorprop-1-en) for 30%, R-125 (Pentafluorethan) for 59 % and R-32 (Difluormethan) for 11 %. Its chemical formula is then: $CH_2F_2 + CHF_2CF_3 + C_3H_2F_4$. Due to the component R32, R452A is lightly flammable and had been classified as an A2L refrigerant by ASHRAE. The composition insures an acceptable compromise between GWP and flammability.

Considered as a good drop in because of its volumetric refrigeration capacity, they all also recommend to use it to replace R404A in refrigerated transport unit in service. Some transporters have already decided to replace systematically R404A during the maintenance operation to avoid any risk of shortage and extra-cost at short.

Until now, no alternative has been presented to replace the other HFC’s in road refrigerated transport units such as R134a and R410.

Alternatives solutions are available with other technologies such as cryogenic refrigeration units. The direct cryogenic devices tested in the seventies and re developed few years ago have been soon abandoned for safety reasons. The direct injection of nitrogen in the body was dangerous for operators. The indirect cryogenic devices using $N_2$ or $CO_2$ are still developing on the market with the solutions proposed by Air Liquide, Thermoking or Cryofridge. They will never represent a universal solution and would not replace the compression systems in all its applications, nevertheless they present some interesting advantages were the outside temperature is not too hot.

### The Specificity of Marine Refrigerated Containers

Most of the marine refrigerated transport is nowadays done by marine containers. ISO containers represent 80 % of the world transport and they are also taking a growing part of the refrigerated transport. The world marine refrigerated containers fleet is evaluated at 2 million unit equivalent 20 feet by the RTOC survey in 2014.

In the marine sector, R134a is the most common refrigerant. The major manufacturers use it in all their units and then, the revolution is not so hard in this sector. The drop in of R134a has not been planned or organised until now. Nevertheless, an alternative is available on the market with $CO_2$. Carrier proposes its model Naturaline© using $CO_2$ as refrigerant. Nevertheless, even if it presents a large environmental advantage, this unit do not meet a large success on the market due to a clear extra cost on a very competitive marine transport market.

### Body Insulation

Most of the insulation of refrigerated transport equipment in terrestrial and marine transport consists of PU foams even if PSE is also utilised. PU foams were originally in the 70's blown with CFC's such as R11 then replaced with HCFC's such as R141b and later with HFC's such as R134a.

Since roughly 2005, most of the foams used in Europe are blown with hydrocarbons such as cyclo-pentane, or $CO_2$. Nevertheless, in numerous countries in the world, F-gases are still in use and it will be a challenge to replace them soon. PU foams F-gas free are still not available at all in developing countries and even in Europe, some manufacturers still blow foams with R134a.

## Medium Term Perspectives for Refrigerated Transport

The refrigerated transport unit manufacturers have not stopped their research and development with short-term alternatives. After New European F-gas in 2015, Kigali amendment in 2016 will extend the European challenge as the worldwide goal and will boosted their actions in innovation.

### Alternative Fluids

Research and development go on in new fluids to replace HFC's in refrigerated transport and first of all to replace R404A.

The most probable medium term alternative will certainly be $CO_2$ or R744. Carrier transicold, on its experience of marine refrigerated transport has already announced field test of this solution on semi-trailer and an early prototype of a $CO_2$ transport refrigeration unit for semi-trailer has been presented in Hannover in 2016. It is quite probable that CO2 vapour compression systems will be developed for the most powerful trucks and trailers units in the coming years. Some researches aim to find a solution to the high pressure of the $CO_2$ transcritic system. An original way to extend the use of $CO_2$ system with a limited pressure is for instance to addition of a small proportion of HFO or HC in the $CO_2$.

Few manufacturers have experienced hydrocarbons on compression refrigeration units. Transfrig in south Africa and Frigoblock in Germany have already tested this kind of units, but even if on a thermodynamic point of view hydrocarbons offer a good alternatives it will be hard to use it on the field for safety reasons. Refrigerated transport faces more complicated solutions than domestic or commercial refrigeration, two sectors in which hydrocarbons are now commonly used in the word.

Some companies are also testing new fluids such as HFOs or blends of HFOs. These alternatives already used for applications in air conditioning but the safety issues are still pending for transport as for car air-conditioning. Mix of HFO, HFC, and other mix of HFC are also on test, but till now no fantastic solution seems to arise.

### Alternative Technologies

If there is no universal alternative technology on test right now, some solutions may take a place on the market.

Sorption systems are experienced by several manufacturers. Thermochemical refrigeration systems are already available for small containers such as Coldway device, but they will certainly be available for vehicles with an upscale of their refrigeration capacity. It is a serious alternative within a few years at least for vans and certainly then for trucks.

Cryogenic systems may enlarge their field of application in transport. Manufacturers are improving their solution to improve their performances and allow their installation on smaller equipment.

Mixed solutions combining cryogenic and compression systems are also under development with project such as Dearman machine that should demonstrate its performances and refrigeration capacities. It could be an alternative for some applications.

### Improvements of Existing Systems and Changes in the System Design

In parallel developments are still ongoing to reduce the load of gases in the refrigeration machines, reduce the leakages of gases in exploitation, maintenance and accidents. Improvements are also expected in the performance.

If the HFC's phase down issue is the major driver of development, it is not the only one. Manufacturers are also working on other developments and first of all the energy consumption and the power of the refrigeration device.

The main trend is the "no motor" refrigeration unit, that is to say units with no diesel unit on. Full electric units have been developed by new manufacturers taking the opportunity of the development of performant batteries and electric moto-compressors. The installation of a generator on the motor of the vehicle has been proposed on the market for years by Frigoblock in Germany, but it is now available at other providers. Hydraulic systems have also been developed using a direct connection on the engine of the vehicle.

## Long-Term Perspectives for Refrigerated Transport

The long-term alternatives are certainly less visible, nevertheless some research axes are already known. The revolution in fluids will occur soon. In a longer perspective, it will still be part of the challenge to find a long-term sustainable solution ending with the regular changes of gas every ten years! These researches will certainly also bring new technologies in refrigerated transport units, nevertheless, vapor compression systems will certainly remain for long the most common technology implemented in transport refrigeration units.

### Natural and other "New" Refrigerants

Natural refrigerant will certainly be developed by several manufacturers especially $CO_2$. This development has been announced for instance by Carrier for trucks and trailers. It will certainly be followed by other manufacturers. If it seems difficult to develop all the products before 2025, a full set of independent units should be available before 2030. This solution should be also implemented broadly in marine transport.

If car industry develop solutions with $CO_2$, they will certainly also be used in refrigerated transport for motor driven units. Car industry may also choose a new refrigerant in the family of HFOs even among hydrocarbons.

In all cases safety issues will arise but the solution of car industry will certainly become the one of motor driven transport refrigeration units for light vehicles. The mass production of components for car industry gives access for transport refrigeration to really competitive solutions. These units represents more than 50% of the total fleet even if with some 2 million units in service and roughly 250 000 new units per year they are far away from car air-conditioning with 700 million units in service and some 100 million new units per year in the world.

For eutectic units $CO_2$ should be an excellent solution, nevertheless the weight of the compressors and then the weight of the machine may occur to be an issue for the machines mounted on small trucks less than 3,5 t.

**Technical Alternatives to Vapor Compression Systems**

The cryogenic systems will certainly go on their development for niche application. The use of new materials and techniques of production will allow a better control for dry ice systems while the diffusion of cold will be improved for liquid systems.

In a long-term perspective, the development of sorption systems will certainly offer alternatives at least for some applications in distribution for instance. Sorption systems including thermochemical devices will certainly also be able to recover lost energy for example from vehicle exhaust, or solar energy.

Magnetic refrigeration meets a tremendous development during the last decade. The first application appeared recently on the market as prototypes for professional cold storage cabinets. Developments have been announced in other applications, among which refrigerated transport. It will first be necessary to enlarge the span of these machines to allow them working with high external temperatures. It is nevertheless a candidate alternative on a long-term perspective.

The development of eutectic systems loaded at home with slurries or hydrates may also offer a competitive solution for distribution in a long term prospective. They will reduce the mass of the equipment increasing the payload of the vehicle. They will also permit the use of energy at the best conditions.

**Last but not Least: Insulation**

The main long-term revolution may occur on the insulation side. Replacing the traditional insulation made of cork… in the seventies, PU foams have dominated the market of refrigerated transport insulation over the last fifty years. They were far more efficient than their predecessors were. If they have made progress for stability, mechanical resistance or durability, their insulation performance did not so much improve during this period. Even worth, with new foaming agents introduced in the 90s to reduce their ozone depletion and then global warming impacts

Vacuum panels have been tested on refrigerated transport equipment and already used in packaging they represent a possible alternative to classical insulation. New insulations materials are also already used on the market for other applications. Aerogels for example present very high insulation performance but till now very poor mechanical capacities. They have been also implemented in packaging and tested on marine containers with interesting insulation results.

## Conclusion

The announced revolution in refrigeration transport is ongoing. Bipartism with two major parties, R404A and R134a and their coalitions is condemned. The king R404A has already been dethroned first by his brother R452A, but cousins have also taken the opportunity to bring some parts of the kingdom. At longer term, the “natural fluids” family and especially $CO_2$ will certainly also take part in the revolution and ask for the power.

Some revolutionaries claim for a more radical change in transport refrigeration solutions and a new regime. They already proposed to replace the vapour compression parliamentary monarchy by the refrigeration republic in which all the technologies would be welcomed, from compression to sorption, from Peltier to magneto-caloric effect and where even the extreme temperatures of cryogenic systems!

For sure the following years will really exciting in refrigerated transport! We are living an modern period!

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