Achieving the green dream by the use of natural refrigerants

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Abstract

According to the latest IPCC report from 2007, a little more than 10% of global warming is related to the use of man made greenhouse gases in refrigeration and air conditioning systems. This has led NGO's and politicians to focus on all options to reduce their use and emission. Since it is much more difficult and politically sensitive to do anything significant about the Carbon Dioxide [CO_2] problem, such man made gases are attracting more attention especially as they are very potent and their use is steadily increasing.

The industrial refrigeration industry has for many years used natural gases such as Ammonia, Hydro-Carbons and Carbon Dioxide instead of the man made greenhouse gases. In some countries in Europe, the use of such manmade gases has been banned and/or taxes have been introduced and/or the bureaucracy associated with them is making it more difficult and expensive to own and operate plants using such gases. This has imposed specific requirements on both contractors and owners/operators including qualification requirements, reporting of leaks and procedures for handling and reporting leak testing and handling of the used refrigerant that is regarded as hazardous waste. Not all these requirements are applicable for systems using natural refrigerants but they do also present their own challenges.

This paper will deal with the challenge of making safe and reliable refrigeration systems based on natural refrigerants. Special focus will be given to chillers typically used for air conditioning with Ammonia and Hydro-Carbons as the refrigerant as presently used in Europe. Some differences in the relevant standards/legislation between Australia, New Zealand and Europe will be considered.

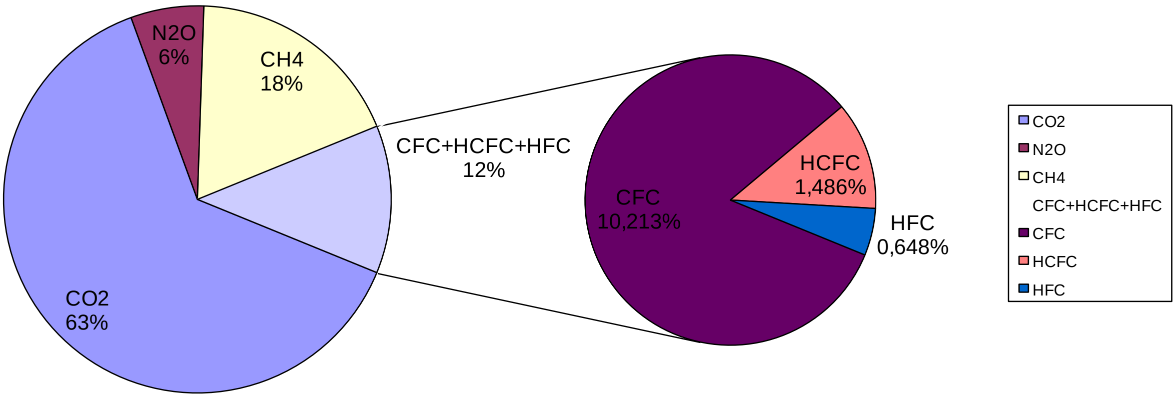
Introduction

The Periodic Table shows that our options for 'Green' solutions are limited. Chlorine and Bromine participate in the depletion of the ozone layer and others e.g. Fluorine, help increase global warming. The Noble gases are not real options for the purpose of normal refrigeration. Helium and Nitrogen are used for small cooling loads at very low temperatures close to the absolute zero. Essentially, we are left with combinations of Nitrogen, Oxygen, Carbon and Hydrogen e.g. Ammonia [NH_3], Caron Dioxide [CO_2], Propane [C_3H_8].

One might think that Nitrogen and Oxygen should be significant contributors to global warming each is present in relatively high amounts in the atmosphere. However, the relatively small molar mass of these two dominating gases makes their contribution insignificant. CO_2 is significantly heavier.

A major factor in global warming is how long the gas can survive in the atmosphere before being broken down into less harmful constituents. Some gases survive for a very long time and will therefore easily accumulate in the atmosphere. R23, for example, has an atmospheric lifetime of 273 [IPCC] and a $GWP_{(100\ years)}$ of 14,800. Ammonia for comparison has zero GWP and zero ODP. Accumulation of such long life, high GWP gases presents a serious high risk to our global climate.

Overall, CO_2 is the single biggest problem but it is also the most difficult to tackle, at least in any radical way. Consequently, there is a sharpening focus on efficiency and avoiding use of the worst offending gases.



Source: IPCC AR4, 2007

Fig. 1: **Radiative forcing by main contributors. CO_2 is the single biggest problem.**

Depending on location, R22 either has been phased out, or is so close to being phased out, that it is no longer worth considering. Unfortunately, in some cases, it is being replaced by HFC gases with a higher GWP. Many politicians and NGO's are responding by imposing new regulations and taxation.

Taxation has proven to be a very effective weapon against the use of HFC. In Denmark, the taxation of HFC usage is linked with the taxation of CO_2 emissions and regulation is via the rules governing waste management. The current CO_2 tax is DKK 0.15 and the end-user price for 1 kg R404A is about 150€/kg. Our industry should expect a similar trend for all gases with high ODP/GWP.

Solutions?

Ammonia

Low charge Ammonia (NH_3) chillers are now in widespread us for air conditioning loads, particularly in Europe. One of the most impressive systems is that serving Terminal 5 of London Heathrow International Airport where four units provide a total cooling capacity of about 25MW. Each unit holds only 1,370 kg of Ammonia.

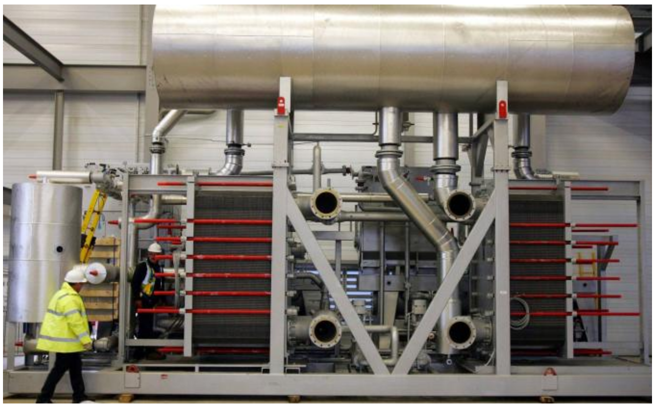


Photo. 1 **One out of four chillers is in place. London Heathrow Intl. Airport**

In addition, numerous small shopping centers have now been equipped with NH_3 chillers in several European countries. In Denmark, a shopping mall recently installed low charge Ammonia chillers to replace a R22 system.

Historically, a flooded system was often used for such chillers and the resulting charge was big. The new breed of low charge chillers is the result of designers taking advantage of modern heat exchanger technology to reduce chiller size, increase efficiency and reduce Ammonia charge.

Table 1 shows the typical charge for modern low charge chillers using the latest shell and plate heat exchanger technology as shown in Fig. 2. The reduction is often to less than a third of that expected in older industrial chillers with separate heat exchangers and vessels.

Small chillers		Recip chiller		Screw chiller	
Cooling capacity [kW]	R717 charge [kg]	Cooling capacity [kW]	R717 charge [kg]	Cooling capacity [kW]	R717 charge [kg]
42	20	233	14	303	19
49	20	294	15	376	22
59	20	346	17	549	32
78	20	357	17	566	32
90	20	440	21	659	37
117	24	464	22	990	56
135	24	536	24		
161	24	588	26		
		690	29		
		715	30		
		878	36		
		921	37		
		1066	41		
		1167	45		
		1398	49		

Table 1: Using modern heat exchangers helps reduce the Ammonia charge.

Photo. 2 A modern low charge Ammonia chiller with Variable Speed Drive and compact heat exchangers.

Lower charges have made it possible to consider using these new chillers for applications that would previously have been considered ‘off-limits’. In particular, commercial applications in urban areas are now serious areas for application of low charge Ammonia chillers.

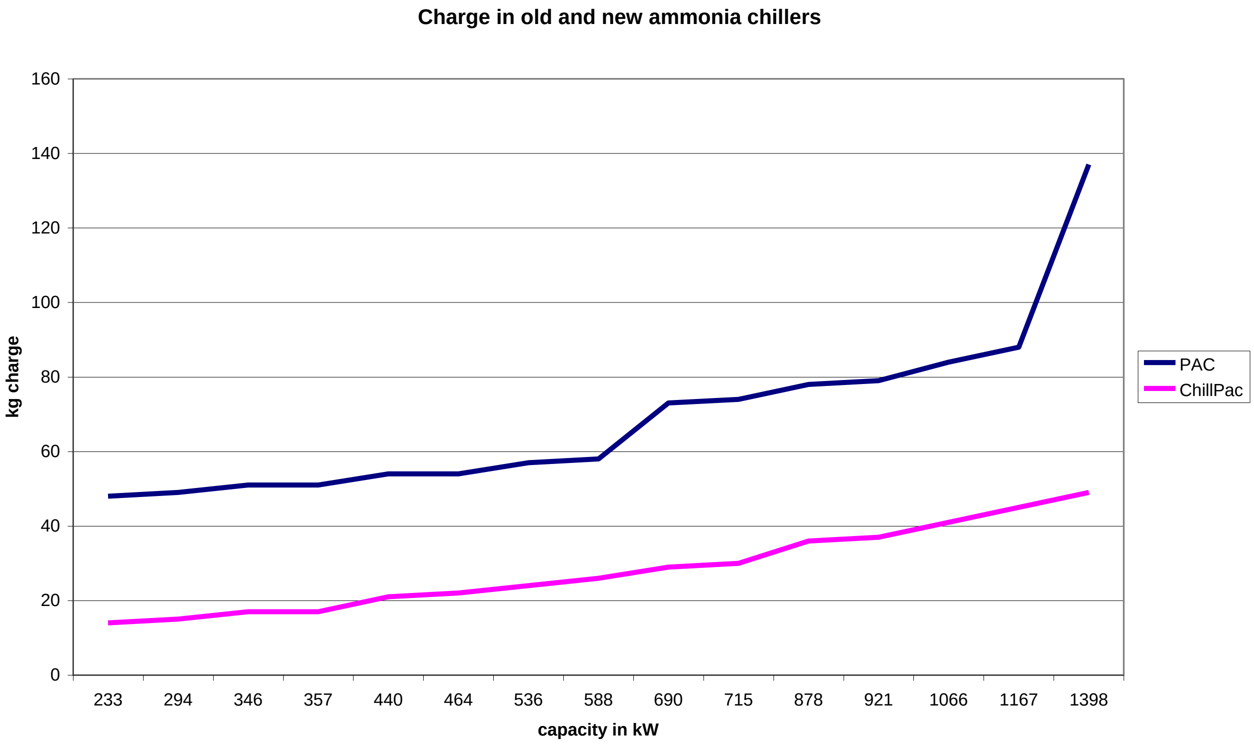


Fig. 2 **The older PAC holds a significantly larger charge than the newer ChillPac type. The PAC has a relatively low charge compared to its predecessors.**

Through proper design, it is possible to reduce the risk and consequences of an Ammonia leak to acceptable levels. If an Air Scrubber is incorporated into the machine room ventilation system it is even possible to reduce the risk of Ammonia leaking to ambient to negligible levels. This has allowed low charge Ammonia chillers to serve relatively sensitive areas such as hospitals and hotels. Of course, the benefit to us all is that the cooling load is satisfied using a refrigerant that has minimal impact on the environment. The important secondary benefit is that, through Ammonia being a highly efficient refrigerant, the owner/operators energy consumption is minimized.

The concern about using Ammonia refrigerant for systems in urban areas is understandable given that it smells, is toxic and irritating in very small concentrations in air and flammable if only within a specific range of concentration in air and with a relatively high ignition temperature. However, it should be noted that the irritating smell of Ammonia, is a property that most engineers consider a benefit. It is a clear sign that a plant is leaking and in need of attention [the old days of it being acceptable to have leaky plants has long gone], and is a clear warning for those not concerned with the plants operation to stand clear.

There have been relatively very few serious accidents involving Ammonia refrigeration systems. Almost without exception, those that have occurred were the result of clear mismanagement of older type, large systems that were essentially custom built to order and allowed to deteriorate over a lengthy period of heavy operation during which multiple changes were made to the system. In fact, most laymen’s concerns about Ammonia arise from scant knowledge of accidents with ammonia in sectors of industry that had little or nothing to do with refrigeration. Note that the global production of Ammonia is currently over 150 million tones and less than 0.3% of that is used in refrigeration plants.

There remains a strong desire on the part of refrigeration engineers to drive for lower and lower charge. Developments will continue and major change is likely to follow improvements in heat exchanger design.

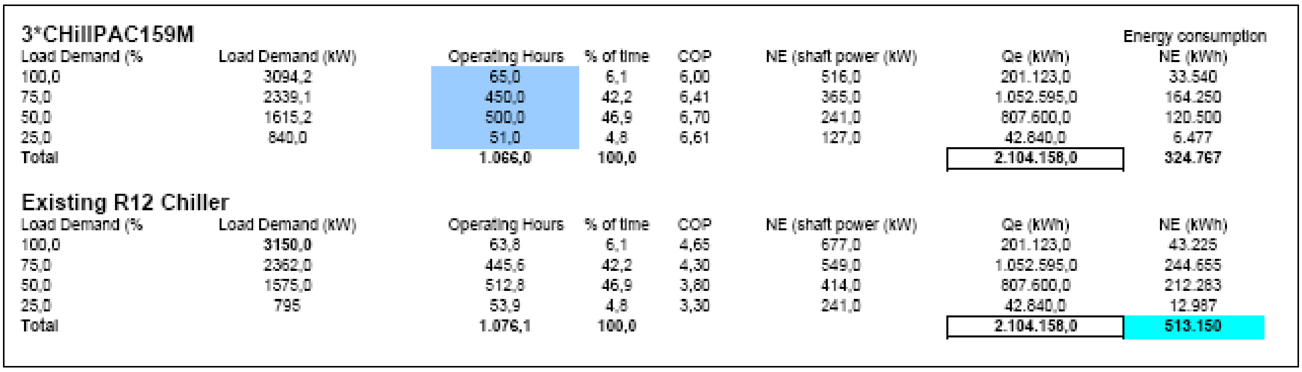
Obviously, safety has to be the first concern when considering what type of chiller to install. Most refrigeration engineers understand that HVAC owner/operators need to be convinced of the benefits of low charge Ammonia chillers and how they can be used safely. However, the recent technical developments mark a definite turning point in that most refrigeration engineers now also accept that such equipment can be applied safely to many commercial applications in urban areas.

Good maintenance is essential for all refrigeration equipment and Ammonia plants are no exception. Proper design of any plant room/site arrangement should allow for easy maintenance of the equipment and safe management of the system in the unlikely event of any problems.

In a resent project a R12 turbo chiller was replaced by three newly developed, inverter driven, low charge Ammonia screw chillers in the middle of a shopping center in Aarhus, Denmark. The required capacity was about 3 MW and, as local regulations forbid use of HFC charges over 10 kg, the owner/operator had to consider alternatives. The result is the successful removal and destruction of 1,200 kg of Ozone depleting material and the installation of a more modern and more efficient refrigeration system using less energy and a refrigerant with zero global warming potential. Tables 2 and 3 show the calculations done for the customer. Each of the Ammonia chillers has a charge of 56 kg.

Absorbed Power [season] kWh	**Old system**	**New system**
Refrigeration	513.15	324.77
Pumps	82.00	64.50
Fans in cooling tower	55.50	44.40
Total absorbed power [season] kWh	650.65	433.67
Reduction in absorbed power kWh	216.99	
Annual CO2 reduction - Tonnes	(216.983 x 0.547) / 1000 = **118.70**	

Table 2: **A break down on the system absorbed power over a season.**



3*CHillPAC159M

Load Demand (%	Load Demand (kW)	Operating Hours	% of time	COP	NE (shaft power (kW)	Qe (kWh)	Energy consumption NE (kWh)
100,0	3094,2	65,0	6,1	6,00	516,0	201.123,0	33.540
75,0	2339,1	450,0	42,2	6,41	365,0	1.052.595,0	164.250
50,0	1615,2	500,0	46,9	6,70	241,0	807.600,0	120.500
25,0	840,0	51,0	4,8	6,61	127,0	42.840,0	6.477
Total		1.066,0	100,0			2.104.158,0	324.767

Existing R12 Chiller

Load Demand (%	Load Demand (kW)	Operating Hours	% of time	COP	NE (shaft power (kW)	Qe (kWh)	NE (kWh)
100,0	3150,0	63,8	6,1	4,65	677,0	201.123,0	43.225
75,0	2362,0	445,6	42,2	4,30	549,0	1.052.595,0	244.655
50,0	1575,0	512,8	46,9	3,80	414,0	807.600,0	212.283
25,0	795	53,9	4,8	3,30	241,0	42.840,0	12.987
Total		1.076,1	100,0			2.104.158,0	513.150

Table 3: **A R12 turbo chiller was replaced by three ammonia chillers in Aarhus West shopping center**

Also in Aarhus, a major hotel and congress center had an Ammonia system installed in 1995/6. Each system has a cooling capacity of 600 kW when cooling water from 12°C to 7°C. The building is very close to the city centre and particularly the City Hall/Theatre. It was critical to minimize any risk of Ammonia escaping from the plant room to avoid creating problems in nearby buildings that include a concert hall and a museum. Consequently, the plant room was fitted with an air scrubber to remove Ammonia from the air. The systems have worked reliably since with absolutely no problems.

Photo. 3: Scandinavian Congress Center in the center of Aarhus uses Ammonia systems with a total cooling capacity of 1,200 kW.

Hydro-Carbons

In the mid 1990's, the first hydro-carbon systems emerged in Sweden. They have proven to be reliable and very efficient. In some cases, they have proven to be even more efficient than the best in the class, namely Ammonia.

Photo. 4: Two indoor Hydro-Carbon chillers.

There are presently over 400 Hydro-Carbon chillers installed in Denmark. The capacity range is from 40 kW up to 400 kW and includes several typical air conditioning loads. One Internet site has eight chillers spread over the roof and providing a total cooling capacity of 1.8 MW for cooling offices and servers. The compressor technology used is readily available hermetic reciprocating compressors and semi-hermetic reciprocating and screw compressors.

Photo. 5: A 60 kW Hydro-Carbon chiller serving a hospital in Aarhus. Installed 2003. [Today, there are chairs and tables arranged nearby for smokers.]

As with low charge Ammonia systems, Hydro-Carbon chillers are designed to use as little charge as possible, to minimize the points of potential leakage and to limit the circulation of the refrigerant to within the confines of the chiller frame. All non-essential valves are eliminated and the type of valve is carefully selected e.g. uncapped valves are a potential leak risk, regardless the type of refrigerant. However, unlike Ammonia, which reacts with Copper, Hydro-Carbons present no major problems with metal compatibility. There are some problems with compatibility with certain polymers and manufacturers have to take appropriate care. Such problems arise with Propylene, [R1270], but it also has a natural smell, which is considered to be an advantage.

Selection of Hydro-Carbon refrigerant is determined by the type of load, temperatures required etc etc. In Australia and New Zealand, it is mandatory to use HC with an added stench so that it "smells like gas". However, there is concern that the added stench can disappear with time as it absorbed by filter driers and in the oil. It may therefore be a false safety. Propylene is naturally smelly and keeps smelling; a fact appreciated by many fire departments.

Photo. 6: **An inverter driven, screw, air-cooled Propane [R290] chiller on test.**

Several customers who have exchanged their HFC or HCFC chillers for a Hydro-Carbon solution have been very impressed by the energy efficiency of the new equipment. As an example, the University Hospital of Aarhus replaced its existing chiller, which had a CoP of 3.0, with a new Propane chiller that performed with a CoP of 4.5.

	Existing plant	New plant
Refrigerant	R22	R290
Charge	100	20
Cooling capacity [kW]	105	105
Energy expenditure [year]	€ 42.252	€ 20.002
Freecooling	No	Yes

Table 4: **Some details from the exchange exercise at the hospital in Aarhus.**

In view of the flammable and potentially explosive nature of Hydro-Carbon and air mixtures [they are explosive in a much weaker concentration than Ammonia and require a much lower ignition temperature], it should not be surprising that in Denmark, Hydro-Carbon system charges are limited to a maximum of 150 g. Nevertheless, all domestic refrigerators and freezers now use R600a and industrial kitchen systems running on R290 are being installed.

Carbon Dioxide

Carbon dioxide [CO_2, R744] has experienced resurgence in use on a variety of applications from server cooling, supermarkets and cold stores through to freezers onboard super trawlers and coffee drying at temperatures around -55°C. 12 years ago, hardly any CO_2 refrigeration systems were in use for typical cooling loads but over 300 systems have been installed globally over the last 8-9 years. Typically, a cascade type system is used with CO_2 operating on the low stage and being condensed in a cascade heat exchanger by a high stage, often using Ammonia.

Use of CO_2 in this way is generally only more efficient than a two stage Ammonia system when operating at very low temperatures [<-48°C]. Hence, CO_2 is often considered for low temperature freezing applications where the lower temperature offers a knock-on benefit in product shelf life. CO_2 can also be used a volatile secondary refrigerant and circulated through air coolers etc in much the same way as could be a glycol. However, the high pressure of CO_2 means that on industrial systems it is presently limited to cooling loads below -10°C.

It is also possible to use CO_2 as a trans-critical refrigerant and such systems are already available from some commercial manufacturers. It is likely to be quite some time however, before we will see such systems applied to industrial or large scale commercial applications.

The industrial refrigeration sector has quickly adopted CO_2 as a refrigerant. One of the first plants on board a ship was installed in 2002 and is still in operation. The plant capacity is 1,350 kW @ -48°C and it serves 11 vertical plate freezers, 1 flake ice machine and hold cooling using 6 CO_2 compressors, (3 available for hot gas defrosting), and 2 ammonia screw compressors on the high stage of the cascade system. The system was installed as a retrofit solution. The old system had 13 tons of R22 onboard and worked at -40°C. The new system has 5.5 tons CO_2 @ -48°C and 600 kg of Ammonia on board. The product freezing time was reduced from 3/3½ hours to 1¾ hours by reducing the temperature from -40°C to -48°C.

Another plant in northern Norway is freezing Salmon. The system is slightly smaller at only 800 kW @ -47°C. The experience with this plant is extremely good and the customer is very satisfied.

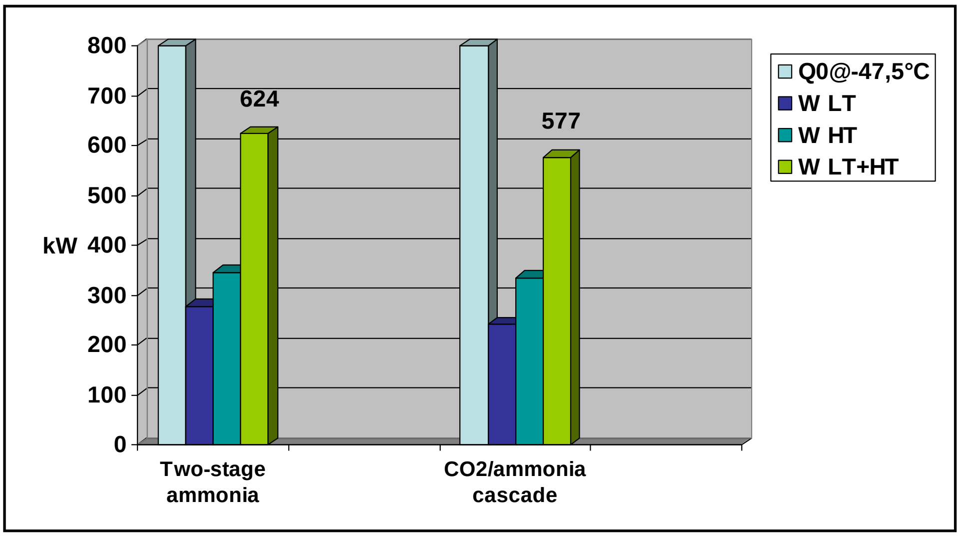


Fig. 3: **Comparison of a two stage Ammonia system and a CO_2/Ammonia cascade system cooling at -48°C.**

In many CO_2 plants, hot gas defrost is used but alternatives such as electric defrost or brine/water defrost might be is used depending of the application. Defrosting is probably the area in which we will see greatest improvement in CO_2 systems in the near future.

Newly developed software, sponsored by some of the CO_2 taxes paid in Denmark, will soon be available as freeware for calculations of mainly CO_2 systems for 920 locations around the world. This tool will enable designers to estimate if a given CO_2 solution is the best option in a given location compared with an alternative solution.

Conclusion

Environmentally friendly refrigerants already exist. They present their own set of challenges but experience has established that Ammonia, Hydro-Carbon and Carbon Dioxide refrigeration systems can be applied safely in urban/commercial environments.

These experiences can be replicated globally. The technology exists; all that is needed is the vision and will.

End