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EXAMPLES OF NH_3/CO_2 SECONDARY SYSTEMS FOR COLD STORE OPERATORS

MEETING THE EMISSION, ENERGY EFFICIENCY AND SAFETY TARGETS

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FOREWORD

TACKLING NON–CO_2 GASES KEY IN CLIMATE CHANGE MITIGATION

"Tackling climate change is one of our times greatest challenges. Huge efforts, good intentions and large ambitions have not yet solved the problem. We must keep searching for more solutions to decrease greenhouse gases. The world's focus is mainly on CO_2 emissions, but we have to include the non – CO_2 gases, as well. That is why a large majority of Members of the European Parliament in 2011 endorsed a Motion for a resolution that calls for rapid reductions of non – CO_2 gases with high Global Warming Potential.

I am happy to see that Danish industry has picked up the challenge put to them by Danish policymakers and developed energy efficient heating and colling technology that does not depend on climate warming gases. I hope that this progress can be an inspiration for other countries to take further action on climate change at a national level and implement measures that will promote climate friendly technologies."

Britta Thomsen
Member of the European Parliament

WHY THIS GUIDE?

The wide acceptance of new technologies depends on a myriad of factors, in the technological, economic and social field, that form part of a complex network of interactions. Both innovators and technology adopters share a common concern for respecting the economic bottom-line and for choosing solutions that provide the highest possible level of investment security while being framed by solid industry support and favourable policy conditions.

The industrial refrigeration industry is no exception to this. While the use of ammonia has not been challenged on grounds of lacking energy efficiency nor overall environmental benefits, the trend towards reducing the refrigerant charge for increased safety is currently changingthe industry.

This Guide was published to examine what role secondary cooling systems combining the safety and efficiency gains of two refrigerants with lowest negative environmental impact can play in the efficient planning and operation of refrigerated warehouse facilities. It addressescold store operators, engineers, contractors and investors,but also regulators involved in advancing sustainable refrigeration technologies in the context of the fight against climate change and ozone depletion. By acquiring a greater level of understanding both politicians and the industry can put into place frameworks allowing for a safe, efficient and economically viable use of NH_3/CO_2 secondary systems.

CHAPTER 1

Provides a brief overview of the cold storage industry's development in Europe and the world, to emphasise the important role a rapidly growing frozen food industry will continue to play in driving more sustainable production patterns.

CHAPTER 2

Highlights the regulatory framework as the basis for investment security and a safe use of refrigerants. This includesinternational agreements, European and national laws and standards, as well as voluntary initiatives supportiveof introducing more sustainable industrial refrigeration technology.

CHAPTERS 3 AND 4

Forming the core of this publication, provide an introduction to the use of secondary refrigeration systems, including a section on the characteristics of the natural refrigerants ammonia (NH_3, R717) and carbon dioxide (CO_2, R744). A dedicated technology section introduces the reader to the overall layout and specific components of these systems, before a section on safety aspectslooks at the requirements and solutions existing for an efficient yet safe use of NH_3/CO_2 systems. Environmental considerations, including direct and indirect emissions, are taken into account to point to benefits and challenges connected with the usage of secondary systems. The final section addresses the economic dimension of using secondary systems, divided by capital cost and expenditures connected with installation, operation and maintenance.

CHAPTER 5

The Best-Practice Guide for End-Users – points out specific considerations for CO_2 systems and those of general nature for the optimal operation of refrigeration systems.

ANNEX CASE STUDIES

Draws attention to 7 selected case studies demonstrating the safe use of secondary systems in practice, and lessons learned.

CHAPTER 1: COLD STORE INDUSTRY PROFILE

COLD STORAGE INDUSTRY: GLOBAL GROWTH TRENDS

According to the 2010 Global Cold Storage Capacity Report of the International Association of Refrigerated Warehouses (IARW), cold storage warehousing is increasing around the world. There is a trend towards increasing capacity of public refrigerated warehouses worldwide that is driven by a greater reliance on the cold chain to meet growing trade and consumption rates of perishable products.

In terms of volume of warehousing, developing countries have made remarkable progress with an annual 20% to 30% growth in cold storage capacity since 1998. Just India and China have occupied 68% in the global capacity growth. In contrast, developed countries have shown much slower growth. The USA has an annual growth rate of 5% and Japan's growth is less than 2%.

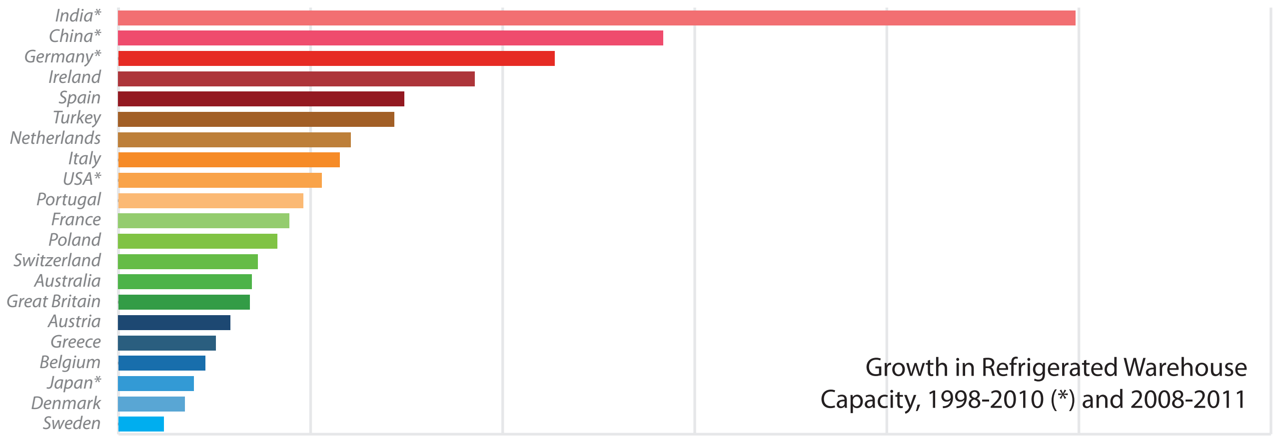

figure 1: Refrigerated warehouse growth by region | source: IARW

EUROPE'S COLD STORE MARKET & MARKET DRIVERS

In Europe, the refrigerated warehouse capacity growth is reported to be around 3% on average with the exception of Germany whose growth rate has been at 11% on average from 1998 to 2010. Among European countries, besides Germany, Ireland also has a relative rapid growth rate of around 9% per year. Cold storage industries in Spain, Turkey, Netherlands, and Italy have relative faster growth among European countries. Countries like Sweden, Denmark, Belgium, Greece and Austria have a low growth rate below 3% and their capacity of refrigerated warehouses tends to be stable and has entered into a low growth stage.

Most European countries have mature cold storage industries and the market is largely saturated, which is one of the important reasons restricting the potential for growth. In addition, the financial crisis and recession in Europe since 2009 has made things worse, directly feeding into the slow growth of the refrigerated warehouse capacity in Europe. According to IARW, Netherlands has the largest capacity of refrigerated warehouses worldwide with 1.15m3 per urban resident. Ireland, Finland, Denmark, Norway, and Germany are among the upper range of the market index with more than $0.3m^3$ per urban resident and most other European countries are listed in the middle level ranging from 0.1 to $0.3\ m^3$ per urban resident.

The IARW has collected data for 25 countries globally showing that in 2008 the capacity of public refrigerated warehouses in these countries was 179.82 million cubic meters (6,350.32 million cubic feet), which represents a 15% increase from 2006 (IARW, 2008).

The following table depicts the situation in a selected number of countries in Europe for which IARW data is available for the years 2006 and 2008, with the data concerning public refrigerated warehouses only (i.e. private warehouses are excluded). Overall, the capacity of public refrigerated warehouses in a selected number of countries in Europe for which data is available was 82.7 million cubic meters in 2008, which represents a close to 32% increase from 2006 levels (62.7 million cubic meters).

COUNTRY	MILLION M^3 IN 2008	MILLION M^3 IN 2006
Austria	0.80	0.80
Belgium	2.00	1.60
Denmark	1.90	1.80
Eastern Europe	1.00	1.00
Finland	1.80	1.80
France	8.50	5.40
Germany	13.40	8.70
Great Britain	5.60	4.40
Greece	0.90	0.90
Ireland	1.70	1.30
Italy	3.50	3.00
Netherlands	12.60	9.00
Norway	1.50	1.50
Poland	0.30	0.30
Portugal	0.80	0.60
Russia	16.00	-
Spain	8.20	2.90
Sweden	0.90	0.90
Switzerland	1.00	0.50
Turkey	0.30	0.30

table 1: Public refrigerated warehouse capacity in Europe | source: based on IARW (2008)

The continued growth in the global frozen food industry and international food trade is expected to provide Europe's cold storage industry with a new stimulus. Domestically, European consumers' high quality standards in food and healthcare products also enhance the growth of refrigerated transportation. According to Pharmaceutical Commerce Magazine's report, the cold-chain logistics has expanded 27% from 2008 to 2011 in Europe.

Growth in the retail industry in Europe and rising food prices also stimulate the growth of the cold storage industry. According to a report by Datamonitor, the grocery market in Europe has rebounded and the total grocery spending grew by 2.2% in 2010. However, the retail market recovery remains fragile and is increasingly saturated. With an uncertain consumer market, the prospect of the retail industry is unclear. Nonetheless, the pressure put on the food retail sector to reduce its carbon footprint – especially on businesses directly exposed to public scruitiny by consumers and non-profit environmental groups, such as supermarkets – have already had an impact on upstream supply chains, including the cold storage industry.

TYPICAL SIZE OF COLD STORAGE FACILITIES AND REQUIRED TEMPERATURE LEVELS

The average size of cold stores ranges from 45,000 to 75,000m^2, which corresponds to a storage capacity of 5,000 to 12,000 euro-pallets, depending on the store layout.

Cold storage facilities usually operate at two temperature levels. They can be differentiated into:

- Those operating in the deep freezing range below -18^{0}C for frozen food stuffs and ice-cream: Frozen produce must be stored below -18°C, howeveraccommodating for a safety margin in the event of equipment failure it is usual to maintain store temperatures between -22°C and -26°C. Some products such ice-cream require lower temperatures (between -26°C and -29°C), while some specialty products such as specific types of sushi must be kept even down to -60°C to retain product quality (RTOC, 2010).
- Those operating in the cooling range around 0°C: Chilled produce is typically held between 0°C and 4°C, although fruit, bakery products and vegetables are stored between 8°C and 12°C (RTOC, 2010). Chilled produce facilities can be further divided into classic cold stores for fresh food stuffs and handling centres with frequent exchange of goods.

Another distinction can be made between public refrigeratedwarehouses and private ones. Companies with storage and distribution needs for their low temperature products may either opt to outsource their needs to a public refrigerated warehouse or cover their needs through privately owned facilities.

GROWING COLD STORE REFRIGERATION DEMAND IN EUROPE

Despite a saturated cold storage market in Europe, the bloc's obligations under the Montreal Protocol treaty provide a stimulus for new refrigeration equipment demand: In the run up to the 2015 deadline by when the use of ozone depleting substances in Europe will be totally banned, the retrofit and replacement of the remaining HCFC refrigeration installations in existing cold store facilities is expected to pick up.

CHAPTER 2: REGULATORY FRAMEWORK

INTERNATIONAL LEVEL

AGREEMENTS ON OZONE DEPLETING AND CLIMATE WARMING REFRIGERANTS

Following the discovery in the 1970s of the ozone depletion due to man-made chemicals, the international community adopted in 1987 the Montreal Protocol on Substances that Deplete the Ozone Layer. To enable the ozone layer to recover, countries have decided to phase-out ozone-depleting substances according to specific time schedules that apply to developed and developing countries. To date, the Montreal Protocol has received universal ratification by all UN countries including the Member States of the European Union.

Today the provisions of the Montreal Protocol only cover the production and consumption of ozone depleting substances. However, the projected increase of high global warming potential HFCs that have been the main the replacement options to HCFCs is now perceived as a major challenge for the world's climate system. Therefore, the Parties are also considering to control the production and consumption of HFCs under the Montreal Protocol, alongside with the Kyoto Protocol that includes HFCs in a basket of 6 greenhouse gases whose combined emissions need to be reduced on schedule.

Proposals in this direction have been submitted in 2009, 2010, 2011 and 2012 for the consideration of the signatories of the Montreal Protocol and several countries are supportive of this process. Indeed, a total of 108 countries have signed a declaration expressing support for taking action on HFCs under the Montreal Protocol, the most fervent supporters being the European Union, the United States, Mexico, Canada, Mauritius and Micronesia. To date, negotiations on this topic are still in progress.

COMPONENT & SYSTEM SUPPLIERS INVEST IN NATURAL REFRIGERANT SOLUTIONS

In the meantime, pre-empting future use restrictions on HFCs, several forward looking companies have focused their R&D efforts in further improving technologies with natural refrigerants. In the field of Industrial refrigeration such companies include big original equipment manufacturers (OEMs) such as MAYEKAWA, Johnson Controls and GEA Refrigeration and worldwide established industrial refrigeration component suppliers such as Danfoss, but also smaller contractors active on national markets that propose natural refrigerant based industrial refrigeration solutions.

EUROPEAN UNION LEVEL

HCFC PHASE OUT IN THE EU[1]

Regulation (EC) No 1005/2009 on substances that deplete the ozone layer is the legal instrument in the European Union that sets out the HCFC phase-out schedule in its member countries.

Accordingly, the use of HCFCs in new equipment has been banned in Europe since early 2000.

Since January 2010 "virgin" HCFCs have been banned for maintaining & servicing of existing systems while at the same time a total ban on supply of virgin HCFCs took effect. Reclaimed or recycled HCFCs can be used to service or maintain equipment until 2015. After this date, the European Union does not allow the use of ozone depleting substances anymore.

Cold storage operators facing the 2015 deadline are thus expected to shift away from the most widely installed refrigerant in most European countries - that is HCFC 22. Many users with multiple systems have planned a replacement strategy to conserve their stock of HCFC-22 refrigerant, setting priorities for which systems to replace or convert first by considerling the age of the plant, likelihood of leakage and ease of conversion (RTOC, 2010). The refrigerant that is recovered from the converted and replaced HCFC-22 systems can be recycled and stored for use in the remaining plants.

Implementing retrofits and replacements of HCFC industrial refrigeration equipment, offers ozone-friendly replacement options ranging from hydrofluorocarbons (HFCs) to natural refrigerants like ammonia and carbon dioxide.

Ammonia alone or combined ammonia and CO_2 systems can cater for the needs of all industrial refrigeration plants in the EU. Where limitations on the use of ammonia exist due to safety distance restrictions, cascade refrigeration systems combining ammonia and carbon dioxide can help circumventing these. Hence, compliance with the HCFC ban in Europe can be easily achieved and at manageable costs given the market availability of alternative technologies and the presence of skilled contractors able to intervene in this field.

EU F GAS REGULATION

The use of HCFCs in newly built refrigeration plants in cold storage facilities is not an option in Europe anymore, as these compounds are being phased out due to their impact on the earth's ozone layer. Besides natural refrigerants ammonia and CO_2, organic compounds hydrofluorocarbons (HFCs) that have been developed as replacements for ozone depleting substances are today widely used in refrigeration applications and cold storage facilities in particular.

However, scientific evidence over the past decades indicates that when these gases escape in the atmosphere they contribute to global warming. To address the issue of emissions related to the use of HFCs, the European Union has adopted a regulation of fluorinated gases (EU F-Gas Regulation No 842/2006), while several Member States of the European Union are domestically taking additional measures. In place since June 2006 in the EU, the overall objective of the F-Gas Regulation in the context of industrial refrigeration plants is to prevent and thereby reduce leakages of high-global warming f-gases such as hydrofluorocarbons (HFCs).

The F-Gas Regulation applies to refrigeration machinery used in cold stores that contains pure f-gas refrigerants and blends, such as R134a, R404A or R507A.

The Regulation requires cold storage operators to compile and report to their competent authorities data with regards to the volumes of fluorinated gases used and their leakage rates as well as measures they put in place in order to reduce these leakages.

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1 - Regulation (EC) No 1005/2009 on substances that deplete the ozone layer, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009R1005:EN:NOT

In addition, it requires refrigerated plants to use qualified and certified personnel for the purposes of servicing and maintaining the machinery containing fluorinated gases.

EU-wide leakage checking standards apply to refrigerated warehouses according to the following schedule:

- Appliances containing over 300 kg of f-gases must be checked every three months
- Automatic leakage detection systems must be installed
- These leakage detection systems shall be checked at least once every 12 months to ensure their proper functioning

Compliance with obligations regarding leak checks is expected to be higher for large companies and large equipment (such as industrial facilities) rather than for small facilities or small equipment. The cold storage industry is well placed in that respect, with the European Cold Storage and Logistics Association (ECSLA) reporting that most companies in France, Germany, Netherlands and Spain carry out regular leakage checks twice a year (Oko-Recherche, 2011).

However, awareness of the provisions of the regulation is considered to be better among contractors rather than facility operators, while operator awareness varies significantly from country to country: High awareness (>80%) in Germany and the Netherlands, medium awareness (>60%) in France and low awareness (<20%) in Spain (Oko-Recherche, 2011).

As regards the future of the regulation, the EU executive body, the European Commission is currently considering the case of revising and therefore making the Regulation more stringent. A first report assessing the effectiveness of the Regulation suggests that more action is required in addressing HFC emissions in the EU, if the bloc is to meet its long-term emissions reduction targets (European Commission, 2011). The same report considers different options for achieving additional reductions of f-gas emissions in the EU, including use and marketing prohibitions for new equipment and products, voluntary environmental agreements at Community level, a tax on sales of HFCs and pre-charged equipment, stricter containment and recovery measures etc. Although it is currently too early to assess what could be the preferred approach for achieving additional HFC emissions reductions in Europe, it may be expected that requirements pertaining to HFC using cold storage facilities be tightened.

VOLUNTARY APPROACHES: EU PARTNERSHIPS, PLATFORMS & PROJECTS

- ICE-E[2] - Improving Cold Storage Equipment in Europe: Funded by the European Union, the ICE-E (Improving Cold Storage Equipment in Europe) project aspires to help European cold store operators reduce their energy consumption and greenhouse gas emissions, though providing a 'Free Cold Store Energy Adviser'. The project, launched in early 2011, will develop benchmarking tools to assess the performance of a particular cold store against data for hundreds of other stores across Europe. A beta version of a simple Excel based model that enables end-users in Europe to compare performance of their cold store when changes to the operation are made has been made available (http://www.khlim-inet.be/media/ice-e/models/Simple_Model_Beta_v2.1.1.xlsx). Users of the Excel model can fill in the data with specifications for their cold store, such as surface areas and insulation type of walls and ceiling, store temperature, type of refrigerant, number of compression stages, temperature of products when loaded, type of defrost, types and number of condenser and evaporator fans, etc. An output file gives the performance results as well as suggestions on how to improve cold store energy consumption. Using the suggested improvements, users can then recalculate the performance of their improved cold store. The development of a second more complex dynamic model is also planned within

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2- ICE-E project website: www.ice-e.eu the project. The project team is also working closely with a selection of cold store operators to shape an understanding of the non-technical barriers that are holding back the uptake of new technologies, such as social, political, economic and organisational contextual issues.

- FRISBEE[3]: Food Refrigeration Innovations for Safety, consumers' Benefit, Environmental impact and Energy optimisation along the cold chain in Europe: The European Union funded 4-year project aims to provide new tools, concepts and solutions for improving refrigeration technologies along the European food cold chain. Mathematical modeling tools that combine food quality and safety together with energy, environmental and economic aspects to predict and control food quality and safety will be developed under the project.
- Sustainable Energy Europe Campaign[4]: The campaign showcases activities dedicated to energy efis on spreading best practice in sustainable energy technology, build alliances and inspire new energy ideas and actions. The current guide has been endorsed by the campaign.
- Intelligent Energy Europe (IEE)[5] & the IEE eLibrary: The Intelligent Energy – Europe (IEE) programme supports the use and dissemination of to clean and sustainable solutions as well the Europe-wide exchange of related knowledge and know-how. It provides funding for creative projects that promote energy efficiency, energy savings, renewable energy and energy diversification. For example, the aforementioned ICE-E project is being funded by IEE. Until 2013, € 730 million is available to fund projects and put into place a range of European portals, facilities and initiatives. Linked to IEE is the IEE eLibrary[6] , which brings together a range of tools and guidebooks on energy efficiency, renewable energy applications and sustainable mobility.
- Energy Efficiency in Industrial Processes (EEIP)[7] : EEIP is a platform for business and policy in Europe, which uses communication, engagement and 'best practice' exchange tools to enable industry and policy to achieve its sustainability and energy security goals while, at the same time, enhancing industrial competitiveness. Its members include industrial end-users, manufacturers of energy saving equipment and parts, Energy Service Companies (ESCOs), IT companies, business and engineering consultancies, industry associations and other interested parties.

NATIONAL LEVEL

NH_3 SAFETY REGULATED AT NATIONAL LEVEL

The use of NH_3 in different countries is much influenced by local health and safety regulations and rules.

These national rules address in a more specific way the need for risk assessment, for certain procedures to be followed regarding incident investigation and reporting and possibly training.

However, national rules and regulations are not harmonised among EU countries, with the requirements scattered throughout multiple national and international codes and standards.

Thus different European countries have very different rates of ammonia refrigeration deployment. For example:

- Germany: safety requirements vary from State to State but are overall not restrictive to the use of ammonia, with over 80% of refrigeration plants in 2009 cooled with ammonia, while about 16% were HFC-based, 2%

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3 - FRISBEE project initiative: http://www.frisbee-project.eu

4 - The website of the initiative: http://www.sustenergy.org

5 - IEE website: http://ec.europa.eu/energy/intelligent/index_en.htm

6 - IEE e-library website: http://www.iee-library.eu

7 - EEIP website: http://www.greencog.eu use CO_2 and less than 1% HCFC22 (UBA, 2011). As an example, in the State of Bavaria, authorisation is required only when the charge exceeds three tons of ammonia as opposed to 150 kg in France.

- France: HCFC22 (R22) is widespread (close to 50% of installed base) that can be partly explained by the restrictive nature of safety regulations applicable to facilities employing small and average systems using ammonia (150 kg to 1,500 kg). Until recently, the regulations dating back to 1998 imposed arbitrary safety conditions such as a minimum distance of 50 meters between an ammonia system and the border of a neighbor property. The resulting needs for vast areas around the ammonia system (approximately one hectar around a simple point) were costly and hard to fulfill by business operators and hence resulted in many obstacles to starting up ammonia plants.

A 2010 French Decree revising the regulation has reduced the minimum distances depending on the design of the installation, making the use of ammonia refrigeration systems somewhat easier. For example the minimum distance is reduced to 10m if among other conditions, all cold production equipment including the condenser are contained in the machinery room and the high pressure accumulator capacity of the circuit contains a mass of ammonia limited to 50kg. If the condenser is located outside the machinery room the minimum distance rises to 15m provided that other requirements are met at the same time, while the minimum distance remains at 50m in other cases.

It has to be noted that in general consulting firms advising cold stores in France are less familiar and rather weary of ammonia. Notably, just crossing the border from France to Spain, the use of ammonia is much more widespread thanks to less restrictive regulations.

There are also stringent requirements in France when it comes to the use of ammonia in premises with access to the public (e.g. in supermarkets): the use of ammonia is permitted only provided that it is used in an indirect system, the ammonia refrigeration system is located in a separate machinery room and the total amount of ammonia in a facility is limited to 150kg.

Overall, restrictive safety requirements seem to have encouraged the continuation of HCFC use in the country at a larger share than in other countries in Europe. However, operators of facilities will soon be facing the 2015 deadline whereby they will not be able to top up their refrigeration systems with reclaimed or recycled HCFCs anymore and will soon after be expected to shift away from their use.

And while regulatory restrictions render the use of traditional direct expansion ammonia systems in France practically very difficult, the use of CO_2 as a secondary refrigerant enables the use of ammonia in indirect systems. Indirect ammonia systems with CO_2 secondary refrigerant, may satisfy the regulatory conditions specified in Frech regulations in a plethora of cases: Ammonia is restricted in a plant room, the system is an indirect one, while ammonia charge is limited below the 150 kg threshold typically to 50-100 kg.

CHAPTER 3: SECONDARY SYSTEMS IN INDUSTRIAL REFRIGERATION

INTRODUCTION

Together with HCFC22 that is now being phased out, ammonia (NH_3 also known as R717) is the most common refrigerant in industrial applications, while carbon dioxide (CO_2 also known as R744) is gaining in low-temperature, cascaded systems where it primarily replaces ammonia (TEAP, 2010).

In new cold storage facilities in particular, the use of natural refrigerants is already an established market in a number of world regions, in the case of ammonia-only systems. The use of ammonia and other HFC-free solutions is not only driven as a means to pre–empt future use restrictions on fluorinated gases, but as an efficient tool to achieve good energy efficiency performance and emissions savings. Also in the near future technical development of alternatives in industrial refrigeration is expected to emphasise NH_3 and CO_2 (TEAP, 2010).

However, with facilities around the world being subject to increasingly stringent safety regulations, owners of large industrial plants and equipment manufacturers start seeking refrigeration solutions that enable them to continue using or start implementing ammonia systems, while ensuring compliance with rigorous (and sometimes restrictive) safety regulations that concern installations that serve public areas or in regions with stringent policies.

CHARGE REDUCTION THROUGH INDIRECT SYSTEMS & CO_2

As a result, various technology solutions leading to a significant ammonia charge reduction have gained in popularity with industrial end-users. In cold store applications, indirect systems have been traditionally implemented by coupling the ammonia system (or the HFC system, though ammonia is the most common refrigerant in industrial refrigeration systems) with a waterbased brine/glycol system, whereby only brine/glycol is circulated in the temperature–controlled area of a facility, with the reduced ammonia charge confirmed in the machinery room area where the appropriate safety devices must be installed.

Indirect systems' most pronounced benefit is, besides the required substantial reduction of refrigerant charge, also lower risk of leakage and today they are a preferred solution in several applications on some markets (UNEP, 2010). Indirect system options have been applied for example in supermarket installations in Europe as of 1995, as well as by US commercial chains as of 2006 as a means to significantly reducing refrigeant charges (50 to 85%) and achieve a much better refrigerant containment (RTOC, 2010).

Another means to achieving significant charge reduction – up to 90% compared to an ammonia–only system – is the use of CO_2 in combination with NH_3. Carbon dioxide has been used for industrial systems in the United Kingdom, France, Germany, the Netherlands, Switzerland, Australia, Japan and the United States of America (Pearson A B). Here, CO_2 is used either:

- As the low stage refrigerant in cascade installations with ammonia, or
- As secondary coolant whereby the carbon dioxide evaporates and condenses at nominally the same pressure

Systems using CO_2 as a "volatile secondary" refrigerant are cost effective thanks to greatly reduced pumping and pipework costs where brine or glycol would have been the alternative (Pearson A B).

The use of the two natural working fluids combines the advantages of ammonia and CO_2, as the latter has good properties, in particular at low temperature, but is not a substitution for ammonia.

As a summary, arrangements where ammonia is used as the primary refrigerant and CO_2 has been adopted either as the secondary refrigerant and/or in the low temperature part of a cascade system gives several advantages including low capital cost and high efficiency. It is probably the most suitable approach for an "environmentally friendly" solution in situations where a direct ammonia system is not feasible (IIR, 2008).

ABOUT NATURAL REFRIGERANTS

Natural refrigerants, especially ammonia, have a long tradition in cold storage logistics. They have been used successfully over the last 130 years. They are recognised as being economically viable, environmentally friendly and very energy-efficient. However, the advent of fluorinated organic compounds in the 20th century saw more and more facilities using refrigerants such as hydrochlorofluorocarbons (HCFCs) and in more recent history hydrofluorocarbons (HFCs).

AMMONIA

- ODP = 0 (Ozone depletion potential)
- GWP = 0 (Global warming potential)

Ammonia is the most common refrigerant in industrial refrigeration systems, especially those for food and beverage processing and storage, however with regional variations around the world (RTOC, 2010) and within Europe in particular.

In the US, currently, ammonia is used in over 95% of industrial applications in food and beverage processing and storage. Ammonia enjoys a high share of deployment also in several European countries, as it is recognised as being economically viable, environmentally friendly and very energy-efficient.

As large facilities around the world are subject to increasingly stringent safety regulations and pressure is being placed on companies to reduce the size of ammonia refrigerant charges, owners of large industrial plants start to use ammonia in conjunction with a secondary refrigerant such as carbon dioxide (CO_2, R744) that enables them to reduce the ammonia charge by up to 90% compared to an ammonia-only system.

CARBON DIOXIDE

- ODP = 0 (Ozone depletion potential)
- GWP = 1 (Global warming potential)
- Not flammable
- Not toxic (EN 378), even though appropriate safety measures still have to be taken

The following provides a table with the characteristics of natural refrigerants as well as chemical refrigerants most commonly used in cold store applications.

Refrigerant	Refrigerant nomenclature	Chemical formula	GWP (100 years)	ODP	Atmospheric Lifetime (years)	Normal boiling point (°C)	Critical temperature (°C)	Critical pressure (bar)	Safety group ASHRAE	Molecular weight (g/mol)	Flammability	Toxicity
Ammonia	R717	NH_3	0	0	< 0.019165	-33.3	132,4	114.2	B2	17.03	Low	High
Carbon dioxide	R744	CO_2	1	0	29,300-36,100	-78.5	31,1	73.8	A1	44.0	None	Low
Propane	R290	C_3H_8	3	0	<1	-42.1	96.7	42.5	A3	44.10	High	Low
Isobutane	R600a	C_4H_{10}	3	0	<1	-11.8	134.7	36.48	A3	58.12	High	Low
Propylene (propene)	R1270	C_3H_6	3	0	<1	- 48	91	46.1	A3	42.08	High	Low
1, 1, 1, 2-Tetrafluoroethane	R134a	$H_2FC\text{-}CF_3$ / $C_2H_2F_4$	1430	0	14	-26.2	100.9	40.6	A1	102.03	None	Low
Chlorodifluoromethane	R22	$CHClF_2$										
	R404A	R-125/R-143a / R-134a (44/52/4)	3920	0	40.36	-44	72	37.32	A1	97.6	None	Low

Refrigerant	Refrigerant nomenclature	Chemical formula	GWP (100 years)	ODP	Atmospheric Lifetime (years)	Normal boiling point (°C)	Critical temperature (°C)	Critical pressure (bar)	Safety group ASHRAE	Molecular weight (g/mol)	Flammability	Toxicity
	R410A	R-32/125 (50/50)	2140	0	16.95	-51.6	70.2	47.9	A1	72.6	None	Low
	R507A	R-125/143a (50/50)	3985	0	40.5	-47.1	70.9	3.79	A1	98.86	None	Low

table 2: Properties of refrigerants typically used in cold store applications | source: based on ASHRAE (2008), Defra (2008), IPCC (2007) Padalkar et al (2010), Proklima (2008)

CHAPTER 4: TECHNOLOGY - NH_3 / CO_2 SECONDARY SYSTEM

CO_2 as secondary refrigerant (brine) encompasses the following properties:

- ODP = 0 (Ozone depletion potential)
- GWP = 1 (Global warming potential)
- Not flammable
- Not toxic (EN 378), even though appropriate safety measures still has to be taken
- Low viscosity: small pumps
- High volumetric cooling capacity: small pipes
- Moderate pressures: 40-45 bars for most of the pump circulated systems

Liquid CO_2 is excellent as a secondary (indirect) refrigerant instead of glycol or brine, as validated by refrigeration scientist Dr S. Forbes Pearson and a small demonstration unit installed in -23°C cold store at Marks & Spencer p.l.c., Kilmarnock, Scotland in the 1990s.

Liquid CO_2 operating pressures (about 40 bars) were outside the range encountered even in the high pressure sides of typical refrigerating systems, however it could be used at temperatures ranging from - 50°C to + 10°C without exceeding the pressures used in modern hydraulic systems (Pearson S.F., 1993) of that time. In the meantime, working with pressures as high as 40 bar or even higher, while still requiring careful consideration, has more recently become standard practice in the HVAC&R sector with the advent of CO_2 subcritical or transcritical refrigeration systems. Subsequently, legislation and codes of conduct have been developed that address pressure, with the EU Pressure Equipment Directive (PED)[8] placing requirements on anyone who designs, manufactures or supplies pressure equipment and assemblies with a maximum allowable pressure greater than 0.5 bar.

Combined with NH_3 as the primary refrigerant, liquid CO_2 is especially suitable for facillities that offer cold storage or combined freezer and cold storage:

APPLICATIONS	TEMPERATURE	SYSTEM TYPE
Cold Storage	-5 to -25ºC	NH_3 Single Stage + CO_2 Brine
Freezer and Cold Storage	-25 to -40ºC	NH_3 Two Stage + CO_2 Brine
Freezer and Freeze Dry	-40 to -52ºC	NH_3 / CO_2 Cascade

table 3: Suitability of CO_2 refrigerant by application, temperature and system type | source: Based MAYEKAWA (2008)

For cold stores with two or more temperature levels a combination of the above mentioned systems could be used. E.g. CO_2 could be used for freezing below -40ºC as a direct refrigerant and for cold storage at -25ºC as brine. In cold storage applications, cascade systems with CO_2 are likely to be slightly less efficient than two-stage NH_3, on par with single stage economised systems, and even more efficient than any system using a secondary fluid thanks to the much lower pumping cost for CO_2 compared to other heat transfer fluids such as glycol, brine etc. (ASHRAE, 2010).

The capacity of NH_3/CO_2 brine systems are typically in the range of 500 kW and can go up to 3 MW. Ammonia is contained in an isolated location (the machinery room), achieving a significant reduction in the ammonia charge, hence reducing the ammonia refrigerant cost while enhancing safety.

No CO_2 compressors are required for this system, only a CO_2 pump.

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[8] - Directive 97/23/EC

A schematic of an ammonia system using CO_2 as a secondary refrigerant is shown in figure 2:

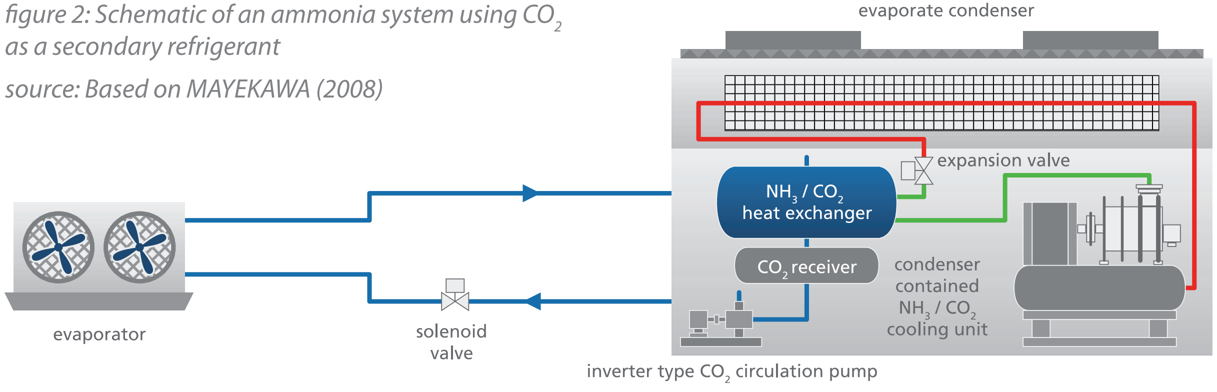

figure 2: Schematic of an ammonia system using CO_2 as a secondary refrigerant

source: Based on MAYEKAWA (2008)

The expanded primary refrigerant (ammonia) evaporates through one side of a heat exchanger, where CO_2 condenses on the other side within a secondary cycle. CO_2 is circulated via pumping into the evaporators. Consequently liquid CO_2 extracts heat, and returns to the ammonia / CO_2 heat exchanger.

Systems using CO_2 as a fluid are relatively simple. The main difference when compared to a water-based brine/glycol system is that the piping and component size on a CO_2 system is considerably smaller for the same capacity.

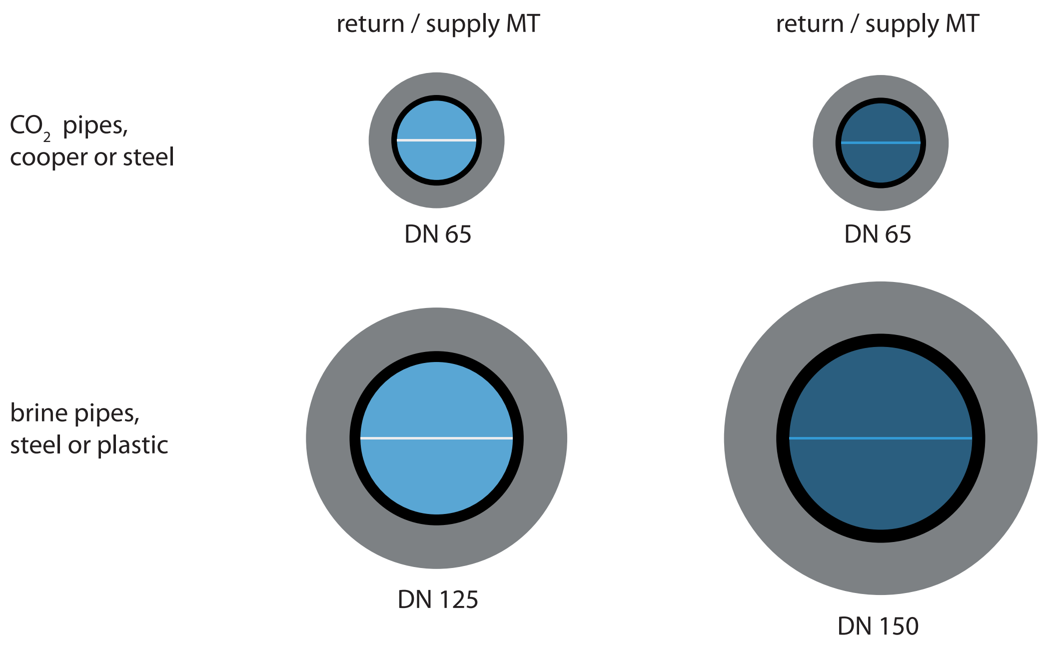

figure 3: Comparison of CO_2 brine and water based brine pipes

source: Mikhailov et al (2011)

The capacities of such systems are typically in the range of hundreds kilowatts and can go up to several megawatts.

In terms of refrigerant charge, the system can rely on 50 - 100 kg of ammonia and on 3,000 kg of CO_2.

KEY COMPONENTS OF AMMONIA-CO_2 PUMPED SYSTEMS - EXAMPLES

Typically, the equipment for ammonia-CO_2 pumped systems is widely available. Component availability is, therefore, not a limiting factor in spreading the technology. Some examples of the key components are listed below:

Examples of ammonia compressors

Both standard piston and screw compressors could be applied. There are no special requirements to ammonia compressors, when compared to other ammonia installations.

image 1a: MAYEKAWA N series ammonia compound screw compressors *source: MAYEKAWA*

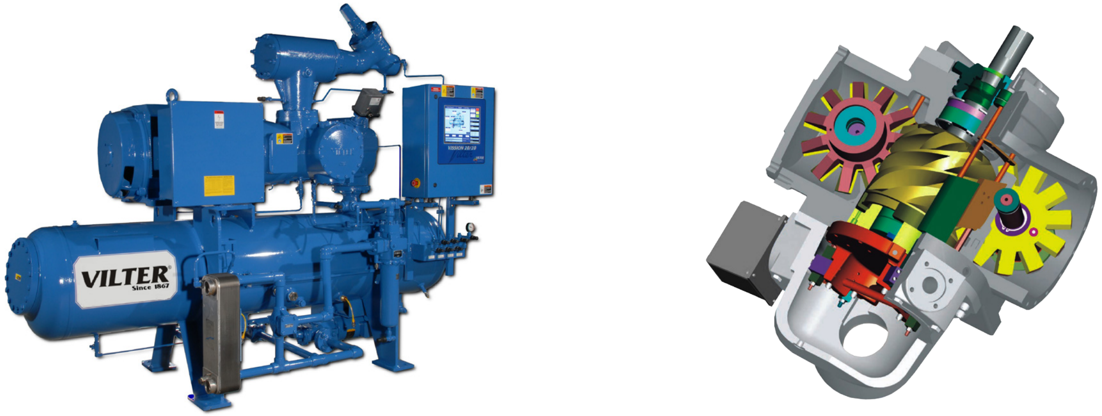

image 1b: Vilter Single Screw VSM/VSS series compressors and units for ammonia *source: Vilter*

image 1c: GEA Grasso screw compressor MC series

source: GEA Refrigeration Technologies

image 1d: SAB 193 screw compressor

source: Sabroe (Johnson Controls)

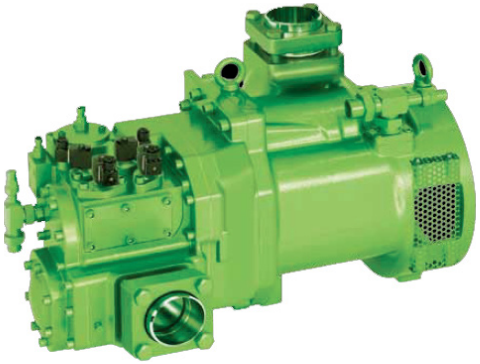

image 1e: Bitzer screw compressor OS.85 series

source: Bitzer

Examples of ammonia CO_2 condensers

Shell and plate, shell and tube as well as plate cascade heat exchangers (CO_2 condensers) are used in CO_2 secondary systems. The choice depends on the design pressure, space requirements and price.

image 2a: Tranter Shell & Plate heat exchanger

source: Tranter

image 2b: Alfa Laval Plate cascade heat exchanger

source: Alfa Laval

Examples of CO_2 evaporators

CO_2 evaporators are similar to those applied in low temperature CO_2 systems. When selecting evaporators it is important to pay attention to the kind of defrost selected (hot gas, water, brine). For example, in case of warm brine defrost double coil evaporators are required. Moreover, CO_2 does not require stainless steel design.

image 3a: Helpman CO_2 evaporat ors

source: Alfa Laval

image 3b: Luvata CO_2 evaporat or

source: Luvata

Example of CO_2 Pump

All major manufactures of refrigerant pumps are offering CO_2 pumps as well. Most recently Grundfos introduced an innovative pump for smaller CO_2 secondary applications.

image 4: Grundfos - refrigerant circulationpumps for CO_2

source: Grundfos Management A/S

Examples of valves and controls

An important requirement for CO_2 valves and controls is the high pressure rating, as well as material compatibility with CO_2. Additional requirements for CO_2 controls is the ability to deal with higher pressure difference and the different dynamics of CO_2, with controls manufacturers such as Danfoss having developed components that fulfil these requirements. Controls also play a key role in reducing refrigerant leakages and improving the safety of both the ammonia and CO_2 system segments: for example ICF valve stations by Danfoss drastically reduce the number of weld and flange connection in systems, reducing leakages and enhancing safety.

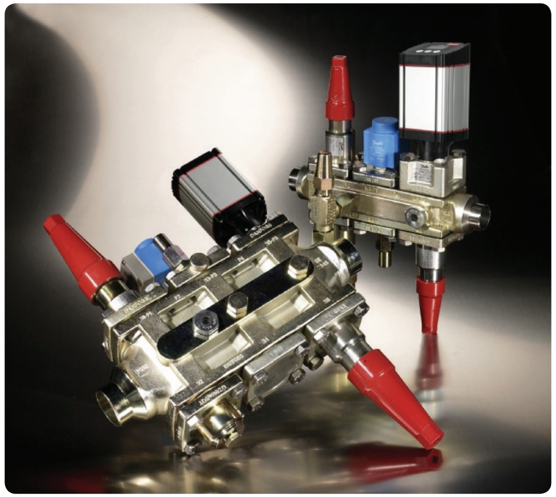

image 5: Danfoss A/S, ICF valve stations for NH_3 and CO_2

source: Danfoss A/S

The following schematic provides an overview of the types of controls and valves and their application in a system using CO_2 as a secondary refrigerant:

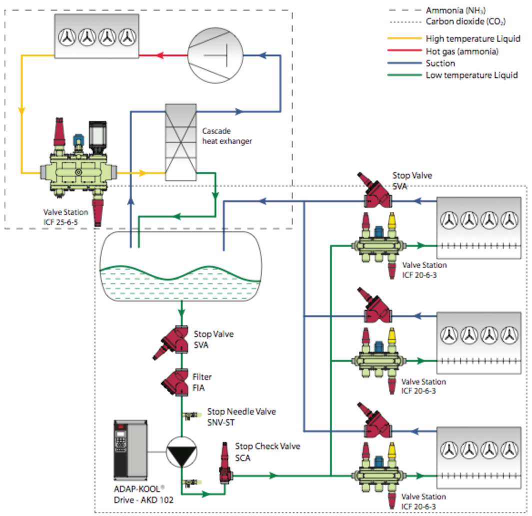

figure 4: overview of controls and valves used in a system using CO_2 as a secondary refrigerant

source: Danfoss

A sizeable impact of cold stores on the environment stems from the use of refrigeration systems that produce cold. The refrigeration systems contribute to greenhouse gas emissions through

- Indirect effect: energy consumption
- Direct effects: leakage of refrigerant, release of greenhouse gases

To reduce the climate impact of refrigeration systems, cold stores may therefore opt for two independent or linked options:

- Improve energy performance of systems; or/and
- Revert to natural refrigerants with low global warming potential (GWP)

Several reasons exist for cold stores to address their carbon footprint:

- Regulatory context (Chapter 2)
- Cost savings, including energy and refrigerant costs (Chapter 4)
- “Self-regulation”
    - » Greening of the supply chain
    - » Listed companies have obligation to audit emissions
    - » Corporate Social Responsibility

DIRECT EMISSIONS

Refrigeration systems directly contribute to global warming through the greenhouse gas effect of fugitive refrigerant emissions. The magnitude of direct refrigerant emissions from a specific HVAC&R using sector depends on a multitude of factors including the number and type of equipment, the refrigerant charge amounts, as well as the different refrigeant types used and their Global Warming Potential (GWP).

Moreover, direct emissions can occur in the different stages of the equipment life cycle as IPCC guidelines (IPCC, 1997) suggests:

- During the manufacturing process / installation of equipment: Refrigerant emissions can occur during the installation of field-assembled systems, such as those typically used in cold stores. Refrigerant handling while charging and topping up the equipment has an impact on this component of direct emissions.
- During the lifetime of equipment: Leaks during the equipment lifetime depend on the application. In industrial processes, the most precise approach to determine emissions would be the collection of invoices for refrigerant used for system maintenance.
- At end of life of equipment: Emissions from equipment at end of life depend on regulatory policies in different countries, and on the recovery efficiency.

This multitude of factors suggests that direct refrigerant emissions will vary significantly by region and by installtion. UNEP’s Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee estimates global emission rates in industrial refrigeration in the range of 10-25% of the total banked refrigerant charge (RTOC, 2010).

A report published by ADEME in 2010 (ADEME, 2010) provided estimates based on published data from various food sectors as collected by the Food and Agricultural Organisation of the United Nations. The report indicates that the global demand for refrigerants in the industrial sector was about 50,000 tonnes, with HCFCs accounting for about half of this. The remainder of the demand was approximately 15,000 tonnes of ammonia, 5,000 tonnes of CFCs (principally in developing countries) and 5,000 tonnes of HFCs, principally in Europe. The estimated size of the banks of refrigerant within existing equipment ranges from 3.5 times the demand to 7 times the demand.

The following table provides estimates of refrigerant demand, banks and emissions associated with the industrial sector in Europe in 2006.

REFRIGERANT DEMAND, BANKS AND EMISSIONS ASSOCIATED WITH THE INDUSTRIAL SECTOR IN EUROPE IN 2006			
	HCFCS	HFCS	R717
2006 refrigerant demand	1,290	2,405	2,939
2006 refrigerant bank	15,819	17,498	20,533
2006 refrigerant emissions (tonnes)	1,390	1,261	800
Emissions (% of 2006 bank)	8.8%	7.2%	3.9%
Global Warming Potential (GWP)*	1,810	2,856	0
Global Warming Impact of 2006 refrigerant emissions (Metric Tonnes of CO_2e Equivalent $MTCO_2e$)	2,515,900	3,601,416	0

table 4: Refrigerant demand, banks and emissions associated with the industrial sector in Europe in 2006

source: based on ADEME (2010) and RTOC (2010)

** Note: GWPs given are based on R22 for the case of HCFCs and the average GWP value of HFCs most commonly used in food processing and cold storage applications, with the individual refrigerant GWP values provided by the 4th Assessment Report of the Intergovernmental Panel on Climate Change: R134a (1,430), R404A (3,922), R410A (2,088) and R507A (3,985)*

The ADEME study points out the difficulty in reconciling figures with other published data, while recognising that other studies report much higher leakage rates for HFCs, noting that poor workmanship during installation can result in higher leakage rates during the first few months of operation until smooth operation is established. At the same time leakage rate of ammonia industrial systems is estimated at about 50% compared to HFC or HCFC leakage rates, consistent with the fact that NH_3 has a characteristic pungent smell which allows leakages to be promptly detected.

The rough calculation in the last row of the above table indicates that industrial refrigeration in Europe accounts for direct refrigerant HCFC and HFC emissions of more than 6 million metric tons of carbon dioxide equivalent ($MMtCO_2$-e), which is equivalent to twice as much the total greenhouse gas emissions of a small country like Malta in the same year. In contrast, the fact that ammonia has a GWP of zero, means that industrial refrigeration plants using ammonia did not contribute to global warming.

INDIRECT EMISSIONS

The energy efficiency of a cold storage facility is calculated based on the energy efficiency of the refrigeration plant and the energy efficiency of the building (taking into account heat flows from goods anf traffic freezing of goods, logistics and personnel). The refrigeration plant is at the core of every cold storage facility and accounts for over 70% energy consumption.

Overall, NH_3/CO_2 fluid system have significantly lower energy consumption compared to traditional systems with NH_3 and water based brines, thanks to:

- Higher evaporating temperature due to lower teperature difference in the heat exchangers and evaporators
- Much smaller pumps
- Lower heat inflow (lower heat gain from outside) due to smaller pipes

TWO MAIN ENERGY CONSUMERS

When considering secondary systems, there are two main energy consumers, namely the compressor and the pump. By employing a NH_3/CO_2 fluid system the energy consumed by both the compressor and the pump is reduced when compared to traditional systems with NH_3 and water based brines:

- The compressor: Maintaining highest possible suction pressure reduces compressor energy use. Indeed, CO_2 encompasses a high heat transfer efficiency factor, at constant evaporating temperature as well as better distribution of the refrigerant in the heat exchangers, characteristics that result in higher suction pressure through:
  - » Lowering the temperature difference in cascade plate heat exchangers (PHE) (by 2-3 K)
  - » Lowering the temperature difference (by 1-3 K) in evaporators
- Pumps: CO_2 is used as a secondary fluid in low temperature applications as it can reduce the energy consumptions for pumps (UNEP, 2010). Low circulation rate, low viscosity and low mass flow of CO_2 as a brine translate into low energy consumption by pumps by up to a factor of 15.

The following table provides estimates of the power consumption by pumps when different secondary refrigerants in case of ca. 500 kW capacity for two temperature levels:

SECONDARY REFRIGERANT	POWER (KW)	
	-10ºC	-20ºC
CO_2	0,97	0,85
$CaCl_2$	13,34	14,22
Hycool	16,02	16,15
Ethylene Glycol	15,87	18,8
Propylene Glycol	14,03	16,68

table 5: pump power consumption for different secondary refrigerants *source: based on Mikhailov et al (2011)*

In addition, when CO_2 is used as brine, the diameter of the discharge and return pipes as well as their insulation are reduced, lowering heat gains and hence system capacity and energy demands. Depending on the ambient conditions, lower heat gain only due to smaller piping could mean more than 5% of the total energy savings.

RESULTS: UP TO 20% ENERGY SAVINGS

Overall, energy savings of up to 20% (and even more in certain cases) can be achieved when opting for a NH_3/CO_2 fluid system over a traditional system with NH_3 and water based brine.

More, specifically CO_2 secondary systems give a possibility of energy savings in the range of 10-20% for high temperature (HT) systems and more than 20-30% for medium temperature (MT) systems (Mikhailov et al, 2011).

SAFETY

Undoubtedly, the advantage of using CO_2 as a secondary refrigerant is safety: On the one hand the ammonia charge is reduced by up to 90% compared to an ammonia-only system and is confined in the machinery room. On the other hand, in case of refrigerant leakage within the storage space, where only CO_2 refrigerant is circulated, the products stored in the cold storage facility are not affected. This does not mean that measures do not need to be taken to avoid CO_2 from being leaked.

Overall, the ammonia and CO_2 charge are distributed in the following way, as separated by inside the production area and outside the production area (machinery room):

OUTSIDE THE PRODUCTION AREA - IN THE MACHINERY ROOM

- Ammonia / CO_2 Brine System
  - » With small ammonia charge at a centralised / self-contained location

IN THE PRODUCTION AREA

- Small CO_2 piping
- CO_2 Evaporative Coils
- No ammonia inside the facility or around the products

figure 5: ammonia and CO_2 charge distribution inside and outside the production area

COSTS

Technical developments since the 1920s have removed many of the barriers to the use of CO_2, which once existed. Systems using CO_2 as a fluid are relatively simple, easy to install while providing energy savings of up to 20% compared to water based brines. CO_2 brine systems have at least 15% lower lifetime cost, when installation, energy and maintenance costs are considered, while capital cost for the CO_2 system is not higher than that of water based brine systems.

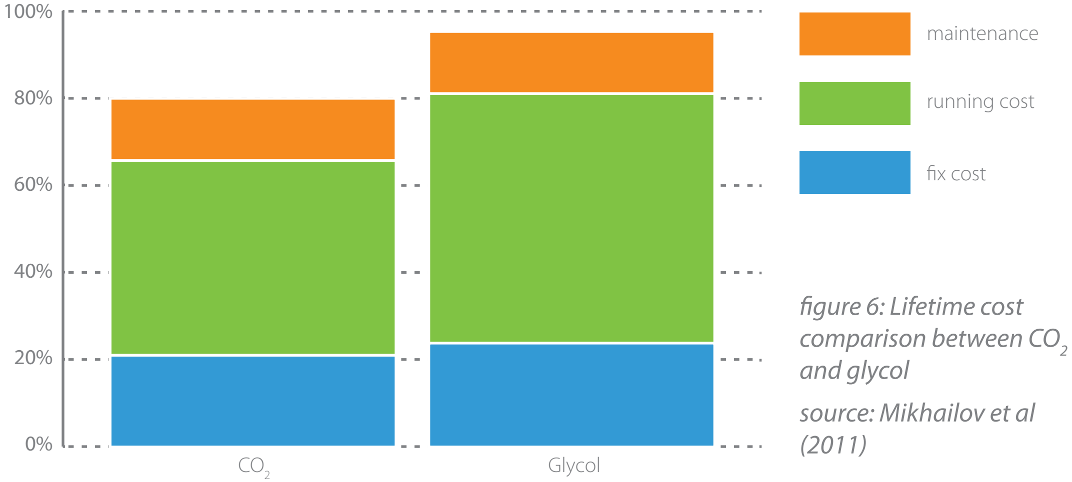

figure 6: Lifetime cost comparison between CO_2 and glycol

source: Mikhailov et al (2011)

CAPITAL COST: COMPETITIVE SYSTEM COST THANKS TO SMALLER COMPONENTS

Systems using CO_2 as a fluid are relatively simple, encompassing an uncomplicated layout. The main difference when compared to a water-based brine/glycol system is that the piping and component size of a CO_2 system is considerably smaller for the same capacity: The circulation rate required for efficient freezing with CO_2 is very low, thus reducing the size of the pumps.

Smaller CO_2 pipes translate to less insulation and smaller valves, while smaller CO_2 pumps translate to smaller frequency drives and a reduced number of pumps. As a result of the smaller components, a CO_2 fluid system is no more expensive than a water-based brine/glycol system. What is more, thanks to the better efficiency CO_2 as a brine, the needs of a given cold store can be catered for by a smaller capacity and hence less costly ammonia chiller.

Overall, the capital cost of a NH_3/CO_2 fluid system is in the same range as that of a traditional system with NH_3 and water based brine.

INSTALLATION COST: SAVINGS OF UP TO 12%

Research has shown that the installation of a refrigeration system using CO_2 as a secondary fluid is no more expensive than a system installed using a water-based brine/glycol.

For an experienced installation company it can be cheaper to install a refrigeration installation for cold storage using CO_2 than a water-based secondary cooling system.

Examples have shown that savings on the installation can be up to 12% when using a CO_2 based refrigeration system.

SIGNIFICANT OPERATION AND MAINTENANCE COST SAVINGS COMPARED TO WATER BASED BRINE

Systems using CO_2 fluid as “volatile secondary” refrigerant are cost effective where brine or glycol would have been the alternative thanks to greatly reduced pumping and pipework costs (Pearson A B).

Energy cost savings of up to 20% can be achieved when opting for a NH_3/CO_2 fluid system over a traditional system with NH_3 and water based brine.

CO_2 secondary systems give a possibility of energy savings in the range of 10-20% for high temperature (HT) systems and more than 20%-30% for medium temperature (MT) systems (Mikhailov et al, 2011).

CHAPTER 5: BEST-PRACTICE GUIDE FOR END-USERS

CONSIDERATIONS OF CO_2 UNIQUE PROPERTIES

CO_2 users must still be highly aware of its unique properties and take the necessary precautions to avoid problems in their refrigeration systems, making the selection of suitable components a key issue.

Although CO_2 brine systems are simple, there are a few aspects that need to be carefully considered:

- Stand still pressure: The pressure rating of a CO_2 systems is between 15 and 35 bar, similar to other refrigerants. However, stand still pressure could rise up to 85 bar (or even higher) if not carefully considered. Using a stand still unit is a simple and cost effective method to address this issue. In case of power failure, the auxiliary cooling system provides temperature control.
- Cascade heat exchanger control in DX systems: On the ammonia side the refrigeration cycle can be controlled using a high pressure float valve, or by direct expansion into the evaporator with an electronic expansion valve and a cascade controller.
- Pump control: The energy consumption of CO_2 pumps is very small, but it is still recommendable to equip them with a small frequency converter. Employing fixed control devices on the evaporators such as regulating valves, renders the flow control and distribution in the evaporator coils much more stable while allowing for further energy savings (for example a small 2 kW pump running with VLT can save up to 7 MWh).
- Defrost: The most typical defrosts for CO_2 brine systems include electrical (similar to standard brines), brine defrost (additional system), water defrost (drain required), hot gas defrost (requires additional vessel and HE heated by HP stage (Danfoss, 2011).

OPTIMISING OPERATION EFFICIENCY THROUGH CONTROLS AND OTHER MEASURES

Further reduction of energy consumption by NH_3/CO_2 systems is possible using smart control algorithms. A good way to improve the efficiency (COP) of the system is to reduce the pressure ratio in the NH_3 compressor (Danfoss, 2011). The 2 ways of doing this include:

- Keep the condenser at the lowest possible pressure
- Keep evaporation at the highest possible pressure

The condenser control is similar to that of traditional systems, where fans can be controlled by a variable frequency drive, and the condensing pressure can vary depending on the ambient temperature.

The management of the suction pressure is another area where there are differences between CO_2 cascade systems and brine/glycol systems. A pressure signal from the CO_2 receiver can be used to control the capacity of the cascade compressors (the NH_3-system). If the pressure in the CO_2 receiver decreases, then the speed of the cascade compressors also decreases, in order to keep up the CO_2 pressure.

Many refrigeration systems are equipped with heat recovery plants so that the waste heat can be used to warm processing water.

ANNEX – CASE STUDIES

This chapter will present case studies where NH_3/CO_2 technology has successfully been implemented.

BELGIAN DISTRIBUTION CENTRE WITH NH_3/CO_2 REFRIGERATION SYSTEM

In 2007 Belgian retailer Delhaize decided to expand its existing distribution centre in Zellik, Belgium with an additional 150,000m^3.

The new building consists of an automated warehouse and loading and unloading bays that need to be continuously refrigerated at a temperature between +1°C and +3°C. The entire new building also needed to be air-conditioned. A technical corridor has been installed above it to accommodate the refrigeration installation, in order to make best use of the storage space.

Ammonia was the refrigerant of choice for refrigerating the building, while it was also decided to limit the refrigerant to the machine room through applying an indirect system, in order to eliminate any product contamination risks and personnel safety risks.

A comparison between glycol and CO_2 as secondary refrigerants was subsequently carried out. The analysis revealed that a NH_3/CO_2 refrigeration installation would be more energy efficient than a NH_3/glycol installation. Not only can evaporation take place at -8°C instead of -10°C, which limits the energy costs (15% annual savings), but the one-off capital outlay is also significantly lower.

Installed by Johnson Controls Industrial Refrigeration BELUX and in operation since 2009, the refrigeration system of the new warehouse building in Zellik features:

- Three SABROE SAB193L screw compressors to compress the ammonia. One of these compressors is frequency controlled, which more easily enables the customer to react to the supply and demand of cooling without having to compromise on efficiency. In total, the compressors provide 2,438 kW at -8°C/35°C.
- CO_2 was chosen as a secondary refrigerant in order to transport the cold to where it is required in the warehouse. The CO_2 is cooled to a liquid via a thermosyphon system (separator with two NH_3/CO_2 plate heat exchangers underneath) by evaporating ammonia.
- To cool the warehouse, eight air handling units have been installed in the technical corridor above, each with a capacity of 100 kW. The loading and unloading bays have been fitted with 36 coolers ranging from 17 kW to 50 kW.

image 6: Three SAB193L compressors produce the refrigeration at Zellik

source: Johnson Controls (2010)

- Two BAC CXV309 axial evaporative condensers condense the ammonia. A cooling unit was also installed to cool the CO_2 buffer tank during a standstill.
- Roof mounted solar panels can supply the energy required for the refrigeration system

Energy and cost savings

The retailer now has a more reliable, energy efficient and environmentally friendly refrigeration installation based on NH_3/CO_2. Compared to a NH_3/glycol installation, Delhaize saves 924 MWh of energy each year and the capital outlay was 5% lower than for the NH_3/glycol solution.

The choice of CO_2 rather than glycol as secondary refrigerant goes some way to reducing energy consumption and subsequently helping the environment.

NH_3/CO_2 REFRIGERATION PLANT FOR FREEZING BAKE-OFF BREAD IN FRANCE

In 2012 GEA Refrigeration France constructed a new refrigera-tion plant on behalf of SAS Lubrano et Fils, located at Sète (France). For freezing of bake-off bread, Lubrano uses three freezing tunnels, which enable optimum freezing quality for dif-ferent products in parallel. Afterwards, the goods are stored in deep-freeze storage rooms.

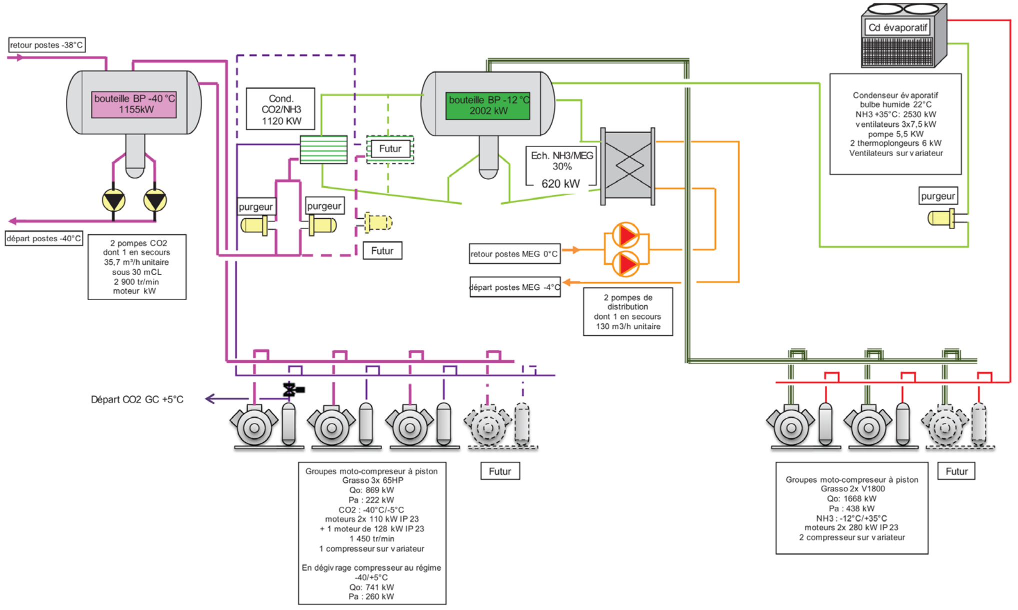

figure 7: Schematic diagram of the refrigeration plant at Lubrano et Fils, in Sète, France

source: GEA

The new refrigeration plant is based on a cascade system that employs the natural refrigerants ammonia (NH_3) in a first step and CO_2 in the second. This plant implements three temperature levels: -40°C for the freezing tunnels, -20°C for the frozen-storage rooms, and -4°C for the water-glycol cycle. The water-glycol system supplies the positive-temperature rooms and var-ious air handling units. The use of CO_2 permits system evapora-tion temperatures of -40°C and additionally enables considerable reduction in the NH_3 charge on site and avoidance of ammonia in the working areas. The refrigeration loads, including a future extension of 250 kW, are around 1150 kW for freezing and approximately 620 kW for chilling.

image 7: GEA Grasso 65HP compressors with variable-speed drive motors for optimised operation under partial load

source: GEA

The high-stage NH_3 unit uses two GEA Grasso V1800 recipro-cating compressors with a total refrigeration capacity at -12/+35°C of 1670 kW, and with variable speed drive motors. The compressors reject heat to one evaporative condenser. The low-stage CO_2 system features three GEA Grasso 65HP reciprocating compressors with total refrigeration capacity at -42/-7°C of 900 kW, and with variable-speed drive motors on a pump separator. These compressors reject heat to a shell-and-plate cascade condenser. The possibility of varying compressor drive speed results in greater energy efficiency under partial load operation – which reduces costs and the product-related CO_2 footprint. Besides refrigeration, the GEA system supplies hot CO_2 gas to defrost the freezer evaporators.

BRITISH DISTRIBUTION CENTRE EQUIPPED WITH CO_2 /NH_3 CASCADE PLANT COMBINED WITH CO_2 SECONDARY SYSTEM

In 2006, British supermarket chain ASDA was looking for a new refrigeration system to replace an existing R22 plant and meet increased operational demands at its distribution center in Lutterworth near Leicester, UnitedKingdom. Independent industrial refrigeration engineering company Star Refrigeration completed an innovative cooling plant installation using a carbon dioxide (CO_2) and ammonia cascade system combined with a CO_2 secondary system, a technology type that the chain has installed since 2002 in the context of its long-term-modernisation programme to replace all HCFC-22-based systems.

The cascade plant operates with ammonia refrigerant in the high temperature stage and CO_2 in the low temperature stage. CO_2 is used as the low temperature fluid in a standard vapour compression cycle, rejecting its heat to the ammonia system. CO_2 is then used as a high temperature volatile secondary refrigerant for chill areas and general air conditioning.

The low stage CO_2 plant has a cooling capacity of 820kW. It supplies low temperature liquid CO_2 to six air coolers in the cold store. The high stage ammonia plant operates with a minimal charge. The plant serves 20 air coolers in 3 chill areas and has a capacity of 2.4MW.

image 8: Inside the machinery room of ASDA's Lutterworth Distribution Centre

source: Star Refrigeration (2007)

The cascade plant provides cooling to four main refrigerated chambers within the storage and distribution facility. The site has a frozen food cold store operating at -25°C and three large chill rooms, operating from +1°C to +13°C.

The new refrigeration plant is located in a purpose built Energy Centre adjacent to the main building. The system has an overall cooling capacity of 3.2MW and serves a total internal volume of around 270,000 cubic metres. The cascade plant's refrigerant charge is predominantly $CO_{2,}$ with an ammonia charge of less than one tonne.

The refrigeration plant is highly energy eeficient, reliable and robust by design to meet the customer's key objectives. The system operates on natural refrigerants and avoids the use of ammonia in populated work areas. The 10-month project formed part of a major refurbishment and extension to the chilled facility at Lutterworth. The site remained fully operational, while the refrigeration plant was being replaced.

ASDA DISTRIBUTION CENTRES WITH CO_2/NH_3 CASCADE + CO_2 SECONDARY SYSTEMS

Two Central Distribution Centres (CDCs) using innovative refrigeration technology by Star Refrigeration were built in 2003 for ASDA in Falkirk and Skelmersdale, United Kingdom. The centres are among the biggest temperature controlled buildings in the UK, with a total combined internal volume of 412,000m^3 - enough space to fit more than 5,000 double decker buses, and a combined cooling capacity of 7MW.

Both centres utilise the natural refrigerants carbon dioxide (CO_2) and ammonia (NH_3). Each site has a cold store and a series of large chill rooms, operating just above 0°C. The refrigeration plant for the -25°C cold store operates as a cascade system, with CO_2 being used as the low temperature fluid in a standard vapour compression cycle, rejecting its heat to the NH_3 system. CO_2 is then used as a volatile secondary refrigerant for the chill areas, being pumped out at –5°C, the condensing temperature for the cold store circuit, and returning as a vapour at the same condition, for condensing by the NH_3 system.

CO_2 as a refrigerant is applied across a range of temperatures and applications from -54°C to +10°C; for low temperature freezing, cold storage, chill applications, air-conditioning and hot gas defrosting.

image 9: Inside the ASDA Distribution Centre

source: Star Refrigeration (2003)

The CO_2 systems utilise components suitable for operation at the higher pressures required for this fluid. The high pressure side of the CO_2 circuit is rated for 51 bar(g), while its low pressure side is rated for 40 bar(g). Oil inject-ed screw compressors are used for the low temperature CO_2 circuit; along side a highly efficient oil retention and recovery system, operating a 3-stage separation process. Their swept volume is a 10th of what would have beenrequired if ammonia had been used as the low temperature refrigerant. Plate & Shell heat exchangers are used for the CO_2 and reliable package. The air coolers used in both the cold and chill stores are designed with circuiting that had been optimised for use with CO_2, delivering higher performance than comparable coolers using either HFC or NH_3 refrigerants.

The defrost system involves taking liquid CO_2, at the -5°C saturated condition and pumping it up to approximately +9°C saturated, the defrosting temperature, via positive displacement pumps. The liquid is then boiled off, using waste heat from the compressor glycol oil cooling system and given around 10°C of superheat, to ensure there is no condensing of the CO_2 in the vapour lines to the heat exchangers. The "hot" gas is then delivered to the air coolers, via individual valve stations.

The energy efficiency of the facility was substantially better than what had been achieved on previous sites, even though they were already achieving "best practice" performance.

In addition, it has been possible to eliminate ammonia from the refrigerated chambers without using a large charge of fluorocarbon (greenhouse warming gas). The total charge of ammonia in the system is 1,000kg, whereas an ammonia glycol system would have required about 1,500kg and a direct ammonia pumped system charge would have been about 15,000kg.

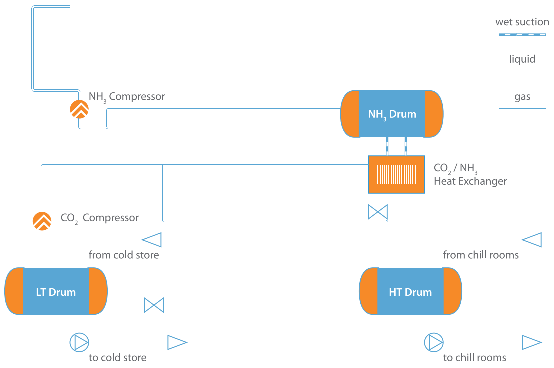

figure 8: Schematic diagram of Carbon Dioxide and Ammonia systems

source: Pearson et al. (2003)

Further environmental benefits have also been achieved. The previous standard system would have used four evaporative condensers, with associated chemical water treatment, but for this system the whole plant heat rejection is achieved with two condensers, so the water treatment is simpler and cheaper.

Alongside these benefits, the use of CO_2 for both the cold and chill stores has allowed much smaller pipework to be used for distribution of CO_2 to the air coolers. With the reduced weight of pipework and associated services to be supported in the roof void it has been possible to simplify the steelwork, resulting in savings in steel capital cost and site programme.

For each of the two facilities, the alternative solution for the end-user would have been a pumped glycol system for the chill store and a separate low charge ammonia system for the cold store. The installed system was nominally the same cost to install, but is cheaper to run; the carbon dioxide pumps have 4kW motors, whereas the equivalent glycol pumps would have required 55kW motors. The annual energy saving is estimated to be about £20,000 (€30,000). It is also expected that maintenance costs for the carbon dioxide system be slightly lower than for the equivalent glycol plant (Pearson A.B.).

EXPERIENCE WITH A NH_3/CO_2 SYSTEM IN A DISTRIBUTION CENTRE IN THE NETHERLANDS

A NH_3/CO_2 fluid solution was commissioned in 2007 for a sophisticated high-rise fruit distribution centre near the port of Rotterdam, in the Netherlands. The building is 20 meters high and can store 12,500 pallets, spread over 15 individually-controlled temperature compartments.

The unique design for the NH_3/CO_2 pump system was implemented by the Dutch contractor Cofely, with all hundred evaporators providing 3,000 kW refrigeration capacity (NH_3 at - 13°C and CO_2 at -8°C).

A NH_3/CO_2 FLUID SYSTEM IN CANADA

Flanagan Foodservice, a leading distribution service company located in Kitchener, Ontario, Canada expanded its facility by 6,000 m^2.

The facility was the first in Canada to implement a dual temperature ammonia/CO_2 fluid refrigeration package system supplied by MAYEKAWA and refrigerates the 360 kW at -15°C for 4,200 m^2 of freezer space and 120 kW at -28°C for 450 m^2 of Ice cream freezer space.

Danfoss supplied the facility with its ICF valve station, a single product platform operating for both natural refrigerants in use at Flanagans.

ICF feeds CO_2 to the evaporators, flooded shell and tube NH_3/CO_2 exchangers. Danfoss supplied as well variable frequency drives and pressure transmitters, which run and control the NH_3 screw compressors and CO_2 pumps.

Moreover, the use of ICM motorized valves in the ICF assembly played a key role in maintaining a stable liquid supply.

EXPERIENCE WITH NH_3/CO_2 SYSTEMS IN JAPAN

By 2008, over 100 installations of NH_3/CO_2 systems operated in Japan.

For example, a MAYEKAWA NH_3/CO_2 system caters for the freezing needs at Seiyu Distribution (Walmart). The installation encompasses the following characteristics:

	NH_3/CO_2 Brine	NH_3 Liquid Pump
Application	Freezer	Freezer
Capacity	59.7 TR (210kW)	59.7 TR (210kW)
NH_3 Evaporation Temp.	-40ºF (-40ºC)	-40ºF (-40ºC)
CO_2 inlet temp.	-34.6ºF (-37ºC)	
CO_2 outlet temp.	-34.6ºF (-37ºC)	
Operating Pressure	174 psig (1.2MPa)	10.4 psig (0.072MPa)
Design Pressure	435 psig (3MPa)	182.7 psig (1.26MPa)
Refrigerant charge	65X2=130kg (286 lbs)	750kg (1,650 lbs) Approx.
Regulations	Reduced NH_3 charge,	Large NH_3 charge, regulated
Operator requirement	None	2 Persons

table 6: characteristics of NH_3/CO_2 system installed at Seiyu Distribution Centre *source: MAYEKAWA (2008)*

The specifications of the CO_2 system include:

Condensing Temp.	95°F (35°C)
Evaporation Temp.	-40°F (-40°C)
CO_2 condensing Temp.	-34.6°F (-37°C)
Air cooler Temp.	Inlet: -20.2°F (-29°C), Outlet: -25.6°F (-32°C)
Room Temp.	**Capacity**
-20.2°F (-29°C)	59.6 TR (210 kW)
Ammonia refrigeration	286.6 lbs (130 kg)
CO_2 Refrigeration	2425 lbs (1,100kg)
CO_2 Pump	5.9 bhp (4.4kW)

table 7: characteristics of NH_3/CO_2 system installed at Seiyu Distribution Centre *source: MAYEKAWA (2008)*

image 10: Inside the ASDA Distribution Centre

source: Star Refrigeration (2003)

RESOURCES

ADEME (2010), Global inventories of the worldwide fleets of refrigerating and airconditioning equipment in order to determine refrigerant emissions, ADEME/ARMINES, April 2010.

AMA Research (2006), Commercial & Industrial Refrigeration Market- UK 2006.

ASHRAE (2010), "Refrigeration Handbook, chapter 3", American Society of Heating, Refrigeration and Air conditioning Engineers, Atlanta.

Basta N. (2010), "New Study Sees Double-Digit Growth in Cold-Chain Services for Life", 30thApril 2010, Pharmaceutical Commerce Magazine Sciences.

Clodic, D. and L. Palandre (2004), Determination of Comparative HCFC and HFC Emission Profiles for the Foam and Refrigeration Sectors Until 2015. Part 1 : Refrigerant Emission Profiles. Centre d'Energetique (Ecole des Mines de Paris/Armines), Report for US EPA and ADEME.

Cryoport (2011), "Why The Frozen Cold Chain Market is Heating Up", Cryoport, Mar 23, 2011, http://www.cryoport.com/biological-shipping-blog/bid/44119/Why-The-Frozen-Cold-Chain-Market-is-Heating-Up

Danfoss (2011), Application guide to CO_2 secondary coolant systems, Danfoss A/S (AC-SMC/MWA), 04-2011.

Datamonitor (2011), Grocery Retailing Market Overview in Europe: Industry Size, Retailer Strategies and Competitor Performance.

Defra (2008), BNCR37: Characteristics of Refrigerants in Relation to Efficiency, January 2008.

European Commission (2011), Report from the Commission on the application, effects and adequacy of the Regulation on certain fluorinated greenhouse gases (Regulation (EC) No 842/2006), http://ec.europa.eu/clima/consultations/0011/draft_report_en.pdf

IARW (2010), Global Cold Storage Capacity Report, International Association of Refrigerated Warehouses.

IARW (2008), Public Refrigerated Capacity by Country, The International Association of Refrigerated Warehouses.

IIR (2008), Ammonia as a Refrigerant, IIR Guide, 3rd Edition, International Institute of Refrigeration.

IPCC (2007), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC/TEAP (2004), Special Report: Safeguarding the Ozone Layer and the Global Climate System, Chapter 4 Refrigeation.

IPCC (1997), Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency. Paris, France.

Johnson Controls (2010), Case study: Delhaize New Fresh 2 Zellik, Belgium

Kruse, H. (2000), Refrigerant Use In Europe, By Horst Kruse, Dr.-Ing., Fellow ASHRAE, ASHRAE Journal, September 2000.

MAYEKAWA (2008), Design Considerations for an NH_3 System Utilizing CO_2 as a Secondary Refrigerant, presentation provided at the 2008 IIAR Ammonia Refrigeration Conference & Exhibition.

Mikhailov, A. et al (2011), CO_2 Secondary Coolant Systems: Energy Efficiency and Control Strategies Considerations, presented at the 23rd IIR International Congress of Refrigeration, Prague, Czech Republic.

Oko-Recherche (2011). Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases, Final Report prepared for the European Commission in the context of Service Contract No 070307/2009/548866/SER/C4.

Padalkar A. S., Kadam A. D. (2010), Carbon Dioxide as Natural Refrigerant, International Journal of Applied Engineering Research, Volume1, No 2, 2010.

Pearson, A.B., Cable, P.C. (2003), A Distribution Warehouse with CO_2 as Refrigerant, Proceedings of the 21st. International Congress of Refrigeration, Washington DC, ICR0624.

Pearson A B, Natural refrigerants for industrial refrigeration, Star Refrigeration Ltd.

Pearson, S.F. (1993), Development of Improved Secondary Refrigerants, The Proceedings of the Institute of Refrigeration, Volume 89, 1992-93, p.72-77.

Proklima International (2008), Natural Refrigerants, Sustainable ozone- and climate-friendly alternatives to HCFCs, Deutshe Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, July 2008.

RTOC (2010), 2010 Assessment Report of the Refrigeration, Aid Conditioning and heat pumps technical options committee, Montreal Protocol on Substances That Deplete the Ozone Layer, United Nations Environment Programme.

Star Refrigeration (2007), Case study Number 27: June 2007 Asda CO_2 Cascade Plant.

Star Refrigeration (2003), Case study Number 8: ASDA Distribution Centre, Skelmerdale.

TEAP (2010), 2010 Assessment Report of the Technology and Economic Assessment Panel, Montreal Protocol on Substances That Deplete the Ozone Layer, United Nations Environment Programme.

UNEP (2010), Alternatives to HCFCs in the Refrigeration and Air Conditioning Sector: Practical Guidelines and Case Studies for Equipment Retrofit and Replacement, United Nations Environment Programme.

UBA (2011), Avoiding Fluorinated Greenhouse Gases Prospects for Phasing Out, German Federal Environment Agency (Umweltbundesamt - UBA).

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shecco is a market development expert helping its partners bring their climate-friendly technologies faster to market. shecco has developed special expertise in sustainable heating, refrigeration & cooling solutions, as well as the transport sector. In the last decade it has supported technology pioneers in the uptake of the natural refrigerants CO_2, ammonia, hydrocarbons, water and air.

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