

Information and case studies for **Australian Businesses**

Natural Refrigerants

CASE STUDIES



Natural refrigerants case studies

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Foreword

Natural Refrigerants

Much of the refrigeration and air conditioning equipment in Australia uses fluorocarbon refrigerants to facilitate the heat transfer process. Fluorocarbon refrigerants are synthetic chemicals which usually have a high global warming potential, and some still have the potential to cause damage to the ozone layer as well if released to the atmosphere.

Alternatives to these chemicals exist that can help to mitigate some of the environmental risks. Often referred to as 'natural' refrigerants because the substances also occur in nature, these alternatives include ammonia, carbon dioxide and hydrocarbons.

These substances have been used as refrigerants for many years, however, they are now finding their way into applications where previously fluorocarbons were the preferred option.

This document has been put together to provide industry decision makers with more information on the potential of 'natural' refrigerants. It includes an overview of each of the alternatives, case studies on how they've been put to use in Australia, and pointers to some sources of further information.

The case studies are written in plain English, and attempt to give a realistic picture of how alternatives to fluorocarbon refrigerants were used in each case — the advantages they provided, the challenges that needed to be overcome, and the drivers behind each project.

Hopefully you will find them and the other resources provided herein useful, and will consider alternatives to fluorocarbon refrigerants next time you have to make a decision regarding air conditioning or refrigeration equipment.

Ammonia



GEA Grasso ammonia chiller being installed on a building roof in Sydney



Plant room of an ammonia refrigeration plant room at a cold storage facility in Victoria

Ammonia is a naturally-occurring substance that can be used as an alternative to fluorocarbon refrigerants in refrigeration systems.

Indeed, ammonia has been in use as a refrigerant since long before the invention of fluorocarbons – it was one of the refrigerants Australian inventor, James Harrison specified for his ground breaking refrigeration machine patented in 1856^[1].

Unlike carbon dioxide and hydrocarbons, ammonia has been used as a refrigerant consistently since the invention of fluorocarbons, however, its use has largely been restricted to large industrial applications.

Basic properties

Ammonia (chemical symbol NH_3 , refrigerant designation R717) is a colourless gas at atmospheric pressure, and has what many would view to be the ideal environmental properties for a refrigerant – it has both a zero ozone depletion potential (ODP) and a zero global warming potential (GWP)^[2].

In isolation, these properties obviously make ammonia an attractive prospect as a refrigerant, given that fluorocarbon refrigerants can have global warming potentials as high as 3900^[2].

Many readers will be familiar with ammonia as an ingredient in household cleaners, fertilizers and other products, and also be familiar with its characteristic odour. Ammonia carries a B2 safety classification, meaning that it has a high toxicity, and also carries a medium flammability risk^[2].

Ammonia is compatible with some, but not all, commonly used refrigeration system lubricants. In particular, it is not suited for use with polyol ester (POE) and poly vinyl ether (PVE) lubricants, and it has only limited applications with poly alkylene glycol (PAG) lubricants^[2].

Potential applications

As mentioned above, for many years ammonia has been the refrigerant of choice in large industrial refrigeration applications (process cooling, cold storage, mining, etc).

In recent years, the focus has broadened to look at other applications that ammonia may be suitable for.

Chillers for building air conditioning, using ammonia as a refrigerant, have been released to the market in recent years, though only a relatively small number of installations in Europe had been reported at the time of writing^{[3][4]}.

One possible reason for the small number of installations to date could be the price of the equipment – estimated to be almost 250% of equivalent standard fluorocarbon refrigerant units^[4]. It has also been suggested, however, that ammonia chillers could operate more efficiently and result in cost savings over the whole life of the equipment^{[3][4]}.

While using ammonia in populated areas can bring about some safety concerns (see section on safety below), ammonia chillers designed for use in building air conditioning systems in Europe have addressed these concerns with the introduction of systems such as containment casings (erecting a structure around the chiller to contain any leaks and 'scrub' the air inside before it is exhausted), ammonia absorption systems and flameproof electrical panels^[4].

The additional safety equipment required will obviously increase costs, however, manufacturers claim that operational energy and maintenance savings will potentially outweigh the increased initial outlay in the long run^[4].

Ammonia's traditional usage in industrial applications is also evolving. Around the world, large ammonia systems are being subjected to increasingly stringent safety regulations and pressure is being placed on companies to reduce the size of ammonia refrigerant charges^[5].

One solution that is being embraced by a number of owners of large industrial plants is to use ammonia in conjunction with a secondary refrigerant such as carbon dioxide in a 'cascade' system, meaning that less ammonia is required to do the same job, and that the ammonia charge can be contained in a plant room or other safe environment. This solution is already in use in Australia, as demonstrated by the case study on CRF Colac presented herein.

As with hydrocarbons, if ammonia is to be used in a system designed for a different refrigerant (such as a fluorocarbon), it should be noted that some modifications will probably be required to ensure compatibility and address the issues associated with ammonia's flammability, toxicity and the standards applying to its usage (see below). The system manufacturer should be consulted before ammonia is substituted in an existing piece of equipment [6].

Safety issues

While ammonia is a toxic substance, it is also found in small amounts in a number of substances we come in contact with on a regular basis. A glass of drinking water can contain as much as 1mg of ammonia, a 200g steak as much as 13mg, and some food additives can contain as much as 18mg [7]. Cigarette smoke and even the air we breathe also contains ammonia in small amounts.

This demonstrates that the human body can deal with ammonia in small quantities. Generally, any amount in the atmosphere below 20 parts per million (ppm) is regarded as not dangerous. At amounts of up to 53 ppm, ammonia's characteristic odour will be noticeable [8].

In amounts of 300-400ppm, prolonged exposure will become unpleasant, and in amounts over 700ppm it can cause burns and serious damage to eyes. In amounts of 5000ppm or above, exposure can be lethal to humans within five minutes [7][8].

Despite these issues, however, ammonia can be used with relative safety in refrigeration systems provided the proper safety measures are put in place.

Australian Standard AS/NZS 1677.2-1998 *Refrigerating systems part 2: Safety requirements for fixed applications* [9] sets out a number of restrictions on the use of B1 and B2 classified refrigerants, which cover ammonia, to promote safety.

In particular, the standard places restrictions on the amount of ammonia that can be used in a system dependent upon its location, the locations where machinery can be installed and the density of occupants allowed in a room containing an ammonia refrigeration system [9].

In addition to this, AS/NZS 2022-2003 *Anhydrous ammonia – storage and handling* [10] sets out specific requirements for the use of ammonia, including the provision of safety equipment, preparation of emergency plans and the requirement for personnel to be properly trained in handling and emergency procedures.

(Please note: this section quote terms which are defined as having specific meanings within the standard – the full standards [9][10] should be consulted before acting on the above information. Note also that the restrictions above apply only to stationary refrigeration and air conditioning systems – different restrictions apply to ammonia used in vehicle air conditioning systems.)

Conclusions

Ammonia has been in consistent use as a refrigerant since the 1800s. It can be a very efficient alternative to fluorocarbon refrigerants in a number of applications, and has been the refrigerant of choice in areas such as industrial refrigeration for many years.

Its environmental properties (zero ODP and zero GWP) are also highly favourable.

Concerns do exist regarding the safe use of ammonia as a result of its toxicity and flammability. Many advances have been made in recent years to minimise these risks, however, including using ammonia in conjunction with other refrigerants in order to reduce and isolate the ammonia charge, and using advanced safety equipment.

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Carbon dioxide



Plant room of a cold storage facility using carbon dioxide refrigerant (above and right)

Carbon dioxide (CO₂) is a substance that has been used in the refrigeration industry since the 1860s^[1].

The use of carbon dioxide as a refrigerant declined between the 1890s and 1930s for a number of reasons, including changes in technology and the introduction of fluorocarbon refrigerants, which were billed as 'safety refrigerants' at the time. Interest in the use of carbon dioxide resurfaced in the 1990s, with discussion of the phase out of ozone depleting refrigerants^{[1][2]}.

Basic properties

Carbon dioxide has an ozone depletion potential (ODP) of zero and a global warming potential (GWP) of 1^[3].

It is generally regarded as a cheap and easily available refrigerant, and many experts also regard it as having a 'unique' set of properties which make it an ideal refrigerant^[1].

In addition to its basic environmental properties, carbon dioxide is non-toxic. It carries an A1 safety classification (the same as most fluorocarbon refrigerants), indicating that it has low toxicity and is non-flammable^[3].

Some experts controversially argue that, although carbon dioxide as a refrigerant carries a GWP of 1, this value should be ignored as the carbon dioxide supplied as refrigerant is usually recovered from the exhaust of industrial processes and therefore would have been released to atmosphere anyway if it were not reused^[1].

Carbon dioxide is colourless, odourless and is also heavier than air. It is the latter property that can cause some safety issues, as if enough carbon dioxide builds up in an enclosed space it will begin to displace oxygen and can cause asphyxiation in anyone present within the space. As carbon dioxide is colourless and odourless, a person in the space will not be able to tell it is filling with carbon dioxide unless proper detectors and alarms are installed*.

When used as a refrigerant, carbon dioxide typically operates at a higher pressure than fluorocarbons and other refrigerants^[4]. While this presents some design challenges it can usually be overcome in systems designed specifically to use carbon dioxide – more issues may be encountered if carbon dioxide is to be retrofitted to a system designed for a different, lower-pressure refrigerant.

Carbon dioxide is compatible with some, but not all, commonly used refrigeration system lubricants. In particular, it is not suited for use with polyol ester (POE) and poly vinyl ether (PVE) lubricants, and it only has limited applications with poly alkylene glycol (PAG) lubricants.^[3]

Potential applications

Carbon dioxide is already being used as a refrigerant in a number of applications around the world, including truck and bus cooling, car air conditioning, in supermarkets and ice skating rinks, in industrial freezers and in large cold storage applications^[1].

Research has also been carried out on the potential for using carbon dioxide as the refrigerant in heat pumps for air conditioning and water heaters^[4].

The availability of equipment rated for carbon dioxide's higher pressure has been an issue in the past, however, the technology is now catching up and many companies offer compressors, evaporators and other equipment suitable for use with carbon dioxide^{[5][6]}.

Carbon dioxide is now being used commonly in what are referred to as "cascade" or "secondary loop" systems, where it is used in conjunction with another refrigerant to maximise efficiency. The Australian case studies presented later provide two examples of this – in cascade with a fluorocarbon refrigerant in a supermarket (Coles Gisborne) and in cascade with ammonia in a freezing and cold storage facility (CRF Colac).

* It should be noted that in this respect, carbon dioxide it is no different to fluorocarbon refrigerants, which are also heavier than air and can cause asphyxiation in similar circumstances.

While there are relatively few installations of this nature currently in Australia, they are becoming more and more commonplace in Europe where companies such as Nestlé have embraced its use ^{[7][8]}.

In his address to the June 2004 “Refrigerants Naturally” conference, Jeff Seabright, vice president of environmental and water resources at the Coca Cola company, stated that “On the basis of the work done over these past four years, we have come to the conclusion that CO₂-based refrigeration is currently the best option for the global needs of Coca-Cola’s sales and marketing equipment, our coolers and vending machines. CO₂ is a natural gas, it is safe and non-hazardous, and its global warming potential is dramatically less than HFCs” ^[9].

Seabright also stated that the company’s preliminary field tests proved the technology to be reliable, in real life circumstances the equipment often used less energy than equivalent equipment using HFC as a refrigerant ^[9].

As of 2006, the company was market testing a range of drinks fridges and vending machines using carbon dioxide refrigerants ^[10].

Safety precautions

As carbon dioxide falls into the A1 safety classification, AS/NZS 1677.2:1998 Refrigerating systems part 2: *Safety requirements for fixed applications* ^[11] treats it in the same manner as A1-classified fluorocarbon refrigerants.

Some restrictions are placed on the size of the refrigerant charge, with additional allowances made for systems with detectors and alarms fitted, and as carbon dioxide is heavier than air the standard requires “suitable precautions” to be taken to prevent the undue accumulation of refrigerant in occupied spaces in the event of a leak ^[11].

As with fluorocarbon refrigerants, the standard also requires the system to be designed to withstand the refrigerant’s maximum operating pressure ^[11].

(Please note: the full standard ^[11] should be consulted before acting on the above information. Note also that the restrictions above apply only to stationary refrigeration and air conditioning systems – different restrictions apply to refrigerants used in vehicle air conditioning systems.)

Conclusions

A number of experts believe carbon dioxide systems will become more prevalent in the coming years. This is the opinion offered by one expert, Andy Pearson of Star Refrigeration in the United Kingdom ^[1]:

“I believe that they (carbon dioxide systems) will be cheap and they will be very common. We have already seen that the systems installed in all applications show extremely good reliability, and they are also of comparable efficiency to traditional designs. Ongoing research and development will provide further improvements in these areas . . . carbon dioxide refrigeration systems are here to stay for the foreseeable future.”

In 2000, the International Institute of Refrigeration (IIR) identified carbon dioxide’s high working pressure as the main drawback to its use, stating that appropriate equipment needed to be developed for its use to spread ^[12]. This has since taken place, and carbon dioxide refrigeration systems are indeed beginning to gain popularity.

As with other refrigerants, all applications need to be considered on their merits by experts. Its favourable environmental and operational properties make carbon dioxide a competitive option in a number of applications.

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Hydrocarbons



Part of hydrocarbon refrigeration system for making liquid ethylene at temperatures as low as -100°C



Ethylene-propylene cascade system used for recovery of petrol vapour at -80°C . It uses hermetic compressors (green items visible at the edge of the unit)

Hydrocarbons are refrigerants that can be used as an alternative to fluorocarbon refrigerants in some refrigeration and air conditioning applications.

Along with ammonia and carbon dioxide, hydrocarbons were commonly used as refrigerants before the invention of fluorocarbon refrigerants in the 1930s.

Interest in hydrocarbon refrigerants has been revived in recent years with discussions on the phase out of ozone depleting refrigerants and high-profile publicity campaigns from organisations such as Greenpeace, although they have long been used widely in the oil, gas and petrochemical industries, particularly in very large refrigeration systems.

Basic properties

The term 'hydrocarbon' encompasses a range of substances. The hydrocarbons most commonly used as refrigerants are ethane (known as R170), propane (R290), butane (R600), isobutane (R600a) and propylene (R1270).

While each of these substances has a different chemical composition, they all share the same basic environmental properties – an ozone depletion potential (ODP) of zero and a global warming potential (GWP) of 3^[1].

It is these properties that have caused a resurgence of interest in hydrocarbons as refrigerants in recent years – fluorocarbon refrigerants can have global warming potentials as high as 3900^[1], so hydrocarbons would pose a much lesser threat to the environment in the event of a leak.

While the refrigerant designations (the "R" numbers) may not be familiar, many readers will be familiar with the common names of the refrigerants listed above. Hydrocarbons are also used, amongst other things, as barbecue gas and as LPG in our cars.

As most readers will be aware, an important property of all these substances in their other applications is that they are flammable.

Hydrocarbon refrigerants are also flammable, and as a result they carry an A3 safety classification – this means they have a low toxicity, but are in the higher range of flammability^[1]. This does not stop hydrocarbons being used as refrigerants, however, some precautions need to be taken when they are.

Hydrocarbon refrigerants are fully compatible with nearly all lubricants commonly used in refrigeration and air conditioning systems. One major exception to this rule is lubricants containing silicone and silicate (additives which are commonly used as anti-foaming agents) – lubricants containing these substances are not compatible with hydrocarbon refrigerants^[1].

Potential applications

Hydrocarbon refrigerants can be used either in systems designed specifically for their use, or as a replacement in a system designed for a fluorocarbon refrigerant.

If a hydrocarbon refrigerant is to be used in a system designed for a different refrigerant (such as a fluorocarbon), it should be noted that some modifications will probably be required to ensure compatibility and address the issues associated with hydrocarbons' flammability. The system manufacturer should be consulted before a hydrocarbon is substituted in an existing piece of equipment^{[1][2]}.

Another issue that needs to be addressed when replacing any refrigerant is its compatibility with the lubricant being used in the system. As mentioned above, lubricants containing silicone and silicate cannot be used with hydrocarbons.

Hydrocarbons are already being used in a number of applications. In Europe, many models of domestic refrigerators are charged with hydrocarbon refrigerant in the factory. It is estimated that there are at least 100,000,000 household refrigerators in use around the world containing hydrocarbon refrigerants^[3].

According to another report, hydrocarbons have also been used in small air conditioning systems and cold drinking water dispensers, though not in the same numbers as domestic refrigerators [4].

Hydrocarbon refrigerants are also commonly used in large process refrigeration systems in the oil and gas industries.

Various theoretical studies have been carried out on the potential for hydrocarbon refrigerants, or blends of hydrocarbon refrigerants and hydrofluorocarbon (HFC) refrigerants to replace commonly-used fluorocarbon refrigerants.

In 2005, Lee et al compared the performance of hydrocarbon refrigerants R290, R600a and R1270 to that of the commonly-used HCFC refrigerant R22 in a test rig, and found that “in comparison to R22, hydrocarbon refrigerants have similar or better ability and are also environmentally friendly other than flammability” [5].

In 2003, Sekhar, Premnath and Lal conducted experiments on a new refrigerant blend comprising R134a (an HFC) and hydrocarbon refrigerants R600a and R290, with a view to finding a replacement for the CFC refrigerant R12 in domestic refrigerators. They concluded that the blend “has been identified as a promising alternative to be used as a refrigerant in a conventional R12 system” and that, overall, the blend reduced energy consumption by 4 to 11% [6].

Calm and Domanski noted in 2004 that “hydrocarbon refrigerants generally are compatible with the materials used in systems designed for R22 and often can use the same or similar lubricants, however, their substitution requires significant attention to safety issues including application specific considerations” [7].

Some of these considerations are discussed in the following section. Calm and Domanski also make the important point in the conclusion of their paper that “no (one) refrigerant has been identified as a suitable alternative for most applications,” though they identify that some refrigerant blends “offer good options” [7]. Blends can be HFC/HFC or HFC/HC.

While Calm and Domanski’s research was examining all refrigerant types (HFCs as well as natural refrigerants), their point is an important one that is backed up by much of the other research – there is no one solution or ‘magic bullet’. Hydrocarbons may be suitable in some applications, and may not be in others, so every application needs to be carefully assessed on its merits.



A hydrocarbon ice cream freezer from the Unilever field test at the Sydney Olympics

Flammability concerns and usage restrictions

As mentioned above, hydrocarbon refrigerants are flammable and therefore certain restrictions are placed on their use to ensure safety.

Australian Standard AS/NZS 1677.2-1998 *Refrigerating systems part 2: Safety requirements for fixed applications* [8] sets out a number of these restrictions.

The standard states that, for any hydrocarbon system:

- All electrical contacts must be sealed or non-sparking
- The refrigerant charge in a system below ground level must not exceed 1.0 kg
- Sealed systems not exceeding 0.25 kg can be sited in any location
- Systems with charges exceeding 0.25 kg must not be located anywhere where a sudden loss of refrigerant will raise the concentration in the room or occupied compartment above the practical limit (0.008 kg/m³)
- Piping for systems exceeding 1.5 kg must be restricted to the room containing the refrigerant

There are also additional restrictions placed on systems that fall into certain categories:

Category	Additional requirements
Hospitals, prisons, theatres, supermarkets, schools, hotels, restaurants, dwellings	<ul style="list-style-type: none"> • Refrigerant charge must not exceed 1.5 kg per sealed system • Refrigerant charge must not exceed 5.0 kg in special machinery rooms for indirect systems
Offices, small shops, small restaurants, places for general manufacturing and where people work	<ul style="list-style-type: none"> • Refrigerant charge must not exceed 2.5 kg per sealed system • Refrigerant charge must not exceed 10.0 kg in special machinery rooms for indirect systems
Industrial, cold stores, dairies, abattoirs, non public areas of supermarkets	<ul style="list-style-type: none"> • Refrigerant charge must not exceed 10.0 kg in humanly occupied spaces • Refrigerant charge must not exceed 25.0 kg for systems with high pressure side in special machinery rooms • No restrictions are placed on the charge size if all parts of the system containing refrigerant are in a special machinery room or in open air

(Please note: the above requirements quote terms which are defined as having specific meanings within the standard – the full standard [8] should be consulted before acting on the above information. Note also that the restrictions above apply only to stationary refrigeration and air conditioning systems – different restrictions apply to hydrocarbons used in vehicle air conditioning systems.)

Some Australian states place additional restrictions on the use of hydrocarbons as refrigerants – in particular, state occupational health and safety (OH&S) regulations.

Particular attention should be paid to service practices when working on equipment containing hydrocarbon refrigerant – one study notes that most incidents with hydrocarbon refrigerants result from poor service practices^[3].

Conclusions

Hydrocarbon refrigerants have a number of favourable properties, and in the event of a leak they pose a much lower direct threat to the environment than fluorocarbon refrigerants.

Care needs to be taken to ensure that their flammability will not pose a safety risk, however, when the appropriate precautions are taken hydrocarbon refrigerants can be used effectively in a range of applications.

If a hydrocarbon is to be used as a replacement in a system that wasn't originally designed for a flammable refrigerant, the equipment manufacturer should be consulted to ensure that the system will be compatible.

In some applications, a hydrocarbon refrigerant may be more efficient and use less energy than a fluorocarbon. Each case should be assessed on its merits by an expert, however, and emissions from both direct refrigerant emissions and the energy the system uses should be considered.

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Fluorocarbon-reducing technologies

This summary will vary slightly from the three that it follows – up to this point, we have addressed specific natural refrigerants and their uses.

In this section, however, we will address some technologies that can be used with a number of refrigerant types, and are either allowing for the increased uptake of natural refrigerants or allowing for the reduced usage of fluorocarbons in various market sectors.

Secondary loop systems

Most refrigeration and air conditioning systems use only one type of refrigerant. There is only one “loop” – the system has an evaporator, where the system absorbs heat from the space being cooled, and transfers it via the refrigerant in the loop to the condenser, where the heat is expelled.

A secondary loop system is made up of two refrigeration circuits or ‘loops’, working together as a single system. One loop uses a primary refrigerant, and the other uses a secondary refrigerant.

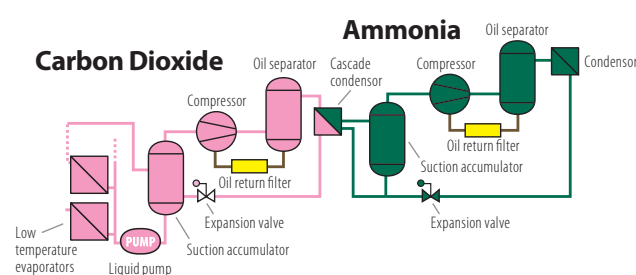
The primary system has all the same features as a single loop system – the difference is that, at the evaporator, instead of exchanging heat with the space that is being cooled, heat is exchanged with the secondary refrigerant, which in turn is removing heat from the space.

This can work with a range of equipment – supermarket cabinets, air conditioners and various other systems. Generally, the secondary refrigerant that is used is non-toxic.

Using a secondary loop configuration can have a number of benefits, including:

- Less primary refrigerant is required, which can in turn reduce costs. If the primary refrigerant is a fluorocarbon, there will be less risk to the environment in the event of a leak.
- As the secondary refrigerant is generally non-toxic, safety concerns in the event of a leak can be reduced.
- The primary refrigerant can be isolated in areas of the building that reduce the risk to people in the event of a leak (such as a plant room).

Other advantages that may also be available include reduced installation times, simplified control systems, improved safety, reduced service costs and better temperature control.



Schematic of a carbon dioxide / ammonia cascade system (courtesy of Grasso)

Secondary loop systems have been around for many years, but the refrigerants employed in them have changed over the years.

They are commonplace in air conditioning for multi-storey buildings, where chilled water is used as the secondary refrigerant that is circulated around the building, and the primary refrigerant (usually a fluorocarbon, in the case of building air conditioning) is contained within a plant room.

Secondary loop systems using a variety of refrigerants have also been used in the dairy and meat industries and in ice cream cabinets.

A variety of substances can be used as secondary refrigerants, including water, ice slurries, brines, glycols, alcohol, silicon oil and liquid carbon dioxide. Different substances will suit different applications, guided largely by the operating temperature of the system.

Historically, water has been used as a secondary refrigerant because it is cheap and readily available. It is unsuitable as a secondary refrigerant in a system operating below 0°C though, as it would freeze in the pipes. As a result, it is most often used in building air conditioning systems, and some process cooling applications.

Brines (a mixture of water and inorganic salts such as calcium chloride or sodium chloride) have been employed as secondary refrigerants as well, but because of their corrosive properties they can shorten the life of pipework and other equipment, reducing efficiency and increasing maintenance costs.

Ice slurries are formed by adding chemicals to water resulting in small ice particles being formed in the fluid. Ice slurries are most commonly used in applications where temperatures between 0 and -5°C are required.

One advantage of using ice slurries is that cooling energy can be stored and “burned off” later as the ice melts. For example, some secondary loop systems generate their ice slurries overnight, making use of cheaper off-peak electricity, for use the next day. Sometimes, this storage can even mean that the primary refrigeration system can be turned off during the day.

Ice slurries are also often employed in the food industry for immersion freezing of fruits, for the production of “desert” frozen fruits such as strawberries. In these cases, the ice slurry is based on a sugar-ethanol solution and research has found that this method reduces losses of valuable fruit enzymes ^[1].

There are two types of glycol that are commonly used as secondary refrigerants: ethylene glycol is toxic, and so is commonly used in non-food applications, and propylene glycol, which is non-toxic and actually sometimes used as a food additive. As it is non-toxic, propylene glycol can be used in food applications and will not present a risk to produce in the event of a leak.

Glycols can be used in conjunction with a corrosion inhibitor, and as a result they have become popular in applications that would previously have employed brines.

In very low temperature applications such as freeze drying, substances such as pure silicon oil or methanol have been employed as secondary refrigerants, reaching temperatures as low as -70°C.

One of the advantages of the abovementioned substances is that they all have a zero ozone depletion potential (ODP) and a zero global warming potential (GWP), so the risk to the environment is greatly reduced in the event of a leak.

One other substance that has been used as a secondary refrigerant in recent years, liquid carbon dioxide, has a GWP of 1. It has been finding applications as a secondary refrigerant in supermarkets, circulating to the frozen food cabinets on the shop floor.

Cascade systems

The cascade system is another alternative to a single-refrigerant system, and is similar in design to a secondary loop system.

A cascade system is made up of two separate but thermally connected refrigeration systems, each of which have a primary refrigerant ^[2]. The refrigerants work in concert to reach the desired temperature, which can sometimes be as low as -100°C in bio-medical applications.

Cascade systems have been used in industrial applications in Australia for some time, and are now starting to be used in commercial situations as well. A common situation is using carbon dioxide as the ‘low stage’ refrigerant in concert with a fluorocarbon, a hydrocarbon or ammonia as the ‘high stage’ refrigerant. CRF Colac (see the case study following) is an example of this arrangement.

Conclusions

While not strictly speaking a natural refrigerant technology, secondary loop and cascade system technology is enabling fluorocarbon refrigerant charges to be reduced and natural refrigerants to be used in new market segments.

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Air and water as refrigerants ^[3]

In addition to ammonia, carbon dioxide and hydrocarbons, air and water are often cited as potential alternatives to fluorocarbon refrigerants.

They are non-toxic, non-flammable and have zero ozone depletion potential and global warming potential. They are also cheap and readily available. They can be used as either secondary refrigerants (as described above) or as the sole refrigerant in a system.

Water is a highly efficient refrigerant over small or medium temperature differentials (0-30°C, for example), however, it has two major disadvantages – in its pure form it can't be used in applications below 0°C (as it will freeze solid) and it requires very large compressors if used as the sole refrigerant in a system.

As a result, water has only been used as the sole refrigerant in a few examples around the world, and all are in very large applications (including a 7MW mine cooling plant in Botswana, and a

2MW chilled water plant at the Lego factory in Denmark – the Lego system uses a compressor with a 1.8 metre diameter).

Water is commonly used as a secondary refrigerant, however, especially in commercial building air conditioning systems.

Air-cycle systems work by compressing air, increasing its pressure and temperature, then cooling and expanding the air. The cold, low-pressure air is used for refrigeration before it is recompressed and the cycle begins again.

Air-cycle cooling systems are used in most commercial and military aircraft, and have also been used in high-speed trains. They are rare in stationary applications, although prototype units have been used at cold stores in Japan.

One of the major barriers to the further adoption of air and water systems is the lack of equipment – at the time of writing, equipment for air or water systems is only being produced in small quantities.

Natural Refrigerants

CASE STUDIES

Hydrocarbon refrigeration at the Sydney Olympics

CASE STUDY



(L-R) Data loggers inside and outside the Unilever ice cream cabinets, and an electricity meter placed on the bottom of the cabinets

Introduction

Two major hydrocarbon refrigeration projects took place during the Sydney Olympics in 2000 – one was carried out by multi-national company Unilever in its ice cream freezers, and the other at the Sydney Superdome by a much smaller company.

Unilever – hydrocarbon ice cream freezers

Multi-national food company Unilever is probably best known by ice cream lovers for its Streets range, with its distinctive heart logo.

The company, which makes everything from toiletries to tea bags, owns around two million ice cream freezers throughout the world and is the global market leader in ice cream sales.

In 2000, in line with its corporate commitment to take on more environmentally sustainable practices, the company pledged that it would not buy ice cream freezers that were charged with hydrofluorocarbon (HFC) refrigerants after 2005 in countries where legal and commercially viable alternatives were available^[1].

Like fellow global business giants McDonalds and Coca Cola, Unilever had been challenged by Greenpeace and the United Nations Environment Programme (UNEP) to take the environmental lead.

The company's Code of Business Principles at the time stated that it was "committed to running its business in an environmentally sound and sustainable manner"^[2].

In recognition of concern about chlorofluorocarbons, it stopped using ice cream cabinets charged with CFC refrigerants in 1995. All of the company's major refrigeration installations use ammonia^[3].

The company states that it was interested in using the natural refrigerant hydrocarbon in "green" ice cream freezers, the subject of this case study, from early on.

Hydrocarbons were favoured because they have zero ozone depletion potential and very low global warming potential (GWP – hydrocarbons have a GWP of 3 - some synthetic refrigerants are as high as 3900^[4]).

Unilever's supply chain director Alan Gerrard says that the company started trialling hydrocarbon refrigerants in India in 1996 and Denmark in 1998^[3].

The move for hydrocarbon freezers coincided with a push by the 2000 Sydney Olympics organisers to embrace 'green' principles in all aspects of the games staged in Australia: guidelines for the Sydney Games stated that CFC, HCFC and HFC-free refrigerants should be used^[5].

As a result, Unilever had 50 hydrocarbon ice cream freezers manufactured for the games.

The company stated that it opted for hydrocarbon because it already had some internal experience with it. It was already available for the domestic market, it has a very similar technology and supplier base and was likely to meet the company's time frame and be within its cost targets [1].

The hydrocarbon chosen was propane, or R290, and the freezers were situated at Sydney's Olympic Park during the Olympics and the subsequent Paralympics.

To compare the operation of the hydrocarbon charged ice cream freezers, Unilever also commissioned 25 freezers using the HFC refrigerant R404A, which is standard in refrigeration systems of this kind. R404A has a GWP of 3800 [4].

Unilever decided to compare their operation in a field test overseen by the Danish Technological Institute.

The test was divided into two parts; the Olympics phase, and a subsequent test phase in which the performance of the freezers was assessed under normal retail use.

The field tests

Once the freezers had completed their duty at the Olympic Park, from the beginning of September 2000, to the end of October 2000, they were taken to a warehouse in Sydney [1].

There the Danish Technological Institute (now known as the CSIRO Energy Centre) and a subsidiary of Denmark's Danish Technological Institute and Unilever gave the cabinets a thorough inspection. Data was collected and the data loggers were re-programmed.

Measuring equipment to measure the temperature outside the cabinet, temperature inside the cabinet and energy consumption of the cabinet in kWh was used. During the test period the temperature data loggers took a measurement every two hours.

A device used to measure energy was mounted in the compressor compartment of the freezers.

The second phase of the field test saw the freezers placed in shops, supermarkets and service stations. In the Sydney area 25 hydrocarbon and 12 R404A freezers were used.

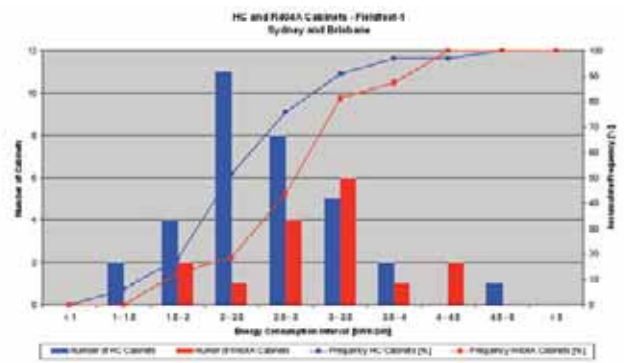
In Brisbane 19 hydrocarbon and 12 R404A freezers were used [1].

According to head of the research, Dr Frank Elefsen, the first freezers were placed in shops from early December, 2000 until mid-July, 2001.

The results – Sydney Olympics

A paper produced by the team headed by Dr Elefsen, titled *Field Test of 75 R404a and R290 Ice Cream Freezers in Australia* and published in *EcoLibrium*® magazine [1] outlines the results derived from the two field tests.

The authors of the report note that two of the hydrocarbon freezers were damaged in the first few days, a power meter did not work on another and a freezer charged with R404A went missing.



Graph showing the energy efficiency of the different ice cream cabinets

It was also noted that the energy consumption on some of the hydrocarbon freezers varied, however, it was suggested that this was a result of each of the hydrocarbon freezers being built manually (essentially, 50 prototype freezers were made – greater consistency would be expected from cabinets mass-produced in a manufacturing environment).

When the data from the cabinets was assessed, however, it was found that the overall energy consumption of the hydrocarbon freezers was considerably less than the R404A freezers. The hydrocarbon average was 2.9 kWh per 24 hours compared with 3.6 kWh per 24 hours for the R404A freezers [1].

The authors also noted that the operating conditions during the Olympics were not typical of normal shop conditions, as the huge numbers of people being serviced resulted in high product turnover and high thermal loads.

Constant opening and closing of the freezers will let outside heat in, and high product turnover means that the freezers had to be restocked with slightly warmer products regularly. Both of these factors meant that the freezers had to work harder than they would normally be expected to, and therefore consumed more energy.

“The energy consumption results are, therefore, not representative for normal use,” the Elefsen team concludes. “The fact that the hydrocarbon freezers functioned well during these tough conditions confirms their reliability, however.” [1]

The results – Sydney and Brisbane store tests

As mentioned above, for the second part of the field test the freezers were placed in service stations, supermarkets and shops in Sydney and Brisbane.

There were 44 hydrocarbon freezers used in the field test. The review found that of them 37 (or 84 per cent) of the freezers operated satisfactorily. Gas leaks and electrical failures were blamed for the failure of the seven remaining freezers. For various reasons the data loggers and measuring equipment did not work on some of the machines.

Sixteen of the 24 R404A freezers used in the field test were regarded to have worked satisfactorily - again, there were some failures with the data loggers and measuring equipment.

The field test team concluded that the hydrocarbon freezers had a consumption of 2.6 kWh per 24 hours compared with 3.1 kWh per 24 hours for the R404A freezers.



One of the test ice cream cabinets

Dr Elefsen's team concluded that based on the two field tests, the new hydrocarbon freezers operated satisfactorily and once other data was taken into consideration the team concluded that the energy consumption of the hydrocarbon freezers was 9 per cent less than the R404A freezers^[1].

The results also confirm that the freezers used less energy when returned to normal operating conditions.

Sydney superdome – hydrocarbon drink fridges

Unilever was not the only company embracing the use of hydrocarbon refrigerants during the Sydney Olympics.

Sunshine Coast-based refrigeration company Maslen Australia worked with the major Games contractor Abigroup to come up with 62 400-litre drink fridges that were used in corporate entertaining areas at the Sydney Superdome.

Company owner John Maslen says he was approached to get involved because of his "long-term interest in environmentally sound refrigeration".

Prior to commencing the project, Maslen and Jan Goedhart of refrigeration consultancy Nutech had already been experimented with retrofitting some standard refrigerators with hydrocarbon refrigerant.

He says that his early results were promising and he was predisposed to using hydrocarbon refrigerants when he was approached to join the Superdome project.

Maslen had meetings with project managers and then began experimenting further with the design.

He says that one drawback was the price of \$2200 per unit – a price tag that looked like it could sink the project before it had really begun. He went back to the drawing board and came up with a simple design featuring a roof-mounted (forced draft) evaporator connected to an R12 compressor and a fan cooled condenser controlled by a domestic thermostat and capillary tube expansion device.

This simpler design reduced the price per unit, \$1600, though it was a sticking point.

"I had very little profit margin to play with, this was very much a labour of love as this was certainly not our core business and I had no plans to make it so," he recalls of the project.

Eventually, Maslen got some support in the form of a \$5000 sponsorship and free gas from Boral in exchange for badging rights.

Maslen says the team studied the regulations and came up with ways to comply with various standards regarding the use of hydrocarbon refrigerant. In many cases, he says, it meant 'leave it out'.

He says the main issue, due to the flammability of hydrocarbon, was to remove potential sources of ignition.

"We replaced anything with electrical contacts with encapsulated electronics and enclosed them in IP (ingress protection) rated boxes - double safety, if you like," he says.

He says the only exception was the thermostat, which was mounted in a sealed IP-rated box but had electrical contacts.

"We simply could not fit electronic thermostats into the budget," he says.

"I made the prototype by hand and loaded it into the back of a ute and drove from Caloundra to Sydney and proudly showed it to the Abigroup. They came back with a list of changes they would like and then we were given the contract."

"I eventually got the prototype back and it is still the best beer fridge I ever owned."

Construction

The final product had an outer shell that was 1mm powder coated galvanised steel.

The inside was made of interlocking Armacell panels made by vacuum forming part recycled PET plastic over part recycled polystyrene insulation and recycled white cardboard to give a smooth finish.

He says the door was a standard Maslen Australia aluminium doorframe with recycled polystyrene insulation and vacuum formed inner liner.

Adjustable shelving was built on a free-standing ladder system.

Maslen notes that there was no warranty on the compressor because of the use of hydrocarbon.

There was a hydrocarbon refrigerant charge of 60 grams.

“No lighting was installed in the single-door fridges and no heater cables were used, to remove potential ignition sources in the event of a refrigerant leak,” he says. “It also helped reach our price target.”

To further minimise any potential ignition sources, all joints in the system were soldered.

Benefits

While Maslen stresses that any of the findings are anecdotal rather than being measured in controlled conditions, he points to some advantages in choosing hydrocarbon.

“It is interesting to note that the hydrocarbon molecule is quite large and is less prone to small leaks than the more popular refrigerants and requires only about 60 per cent of the gas charge by weight,” he says.

He says a smaller charge of a cheaper refrigerant was required, the fridges’ compressors ran cooler and the current draw was between 15 and 20 per cent less.

He says refrigeration mechanics, mindful of the concerns about flammability, were more careful when they were doing their hook-ups, which in Maslen’s view resulted in a lower failure rate for the machines than might otherwise be expected.

Conclusions

Unilever’s experience with hydrocarbon-charged ice cream refrigerators didn’t end at the Sydney Olympics – indeed, the company continued to explore the potential for non-fluorocarbon refrigerants.

After the Sydney and Brisbane field tests, Unilever conducted another, much larger scale trial in Denmark during 2003, in which 800 cabinets were used ^[3].

By the end of 2004, around 15,000 of the cabinets has been installed in 17 European countries. According to the company, laboratory trials have found these models to be 15% more efficient than equivalent HFC refrigerant models ^[6] – an improvement on the 9% efficiency increase observed in the Australian trials.

The company took the Sydney Olympics principle one step further at the 2004 Athens Olympics, where it trialled five similar hydrocarbon-charged ice cream refrigerators powered by solar cells ^[7].

The vice president of global marketing for Unilever ice cream, Gino Coronato, summed up the situation at the 2004 “Refrigerants Naturally” conference ^[8]:

“Why would a Unilever marketing man be talking about working together with competitors such as Coke and McDonalds on refrigeration? And why would consumers be remotely interested in something as boring as freezer technology?” he asks.

“Because, I believe it makes good environmental and marketing sense,” he says. “This premise is based on the belief that great brand design appeals to both the rational and emotional side of our consumers. Unilever’s ice cream business operates nearly two million freezers around the world and we require excellence in refrigeration as a means to remain competitive.”

Coronato also stated that other alternatives to fluorocarbon refrigerants were being tested, including freezers running using thermo-acoustics (using sound pressure instead of the traditional refrigeration cycle).

“Alternatives such as thermo-acoustics will continue to be tested, particularly in the US where hydrocarbons have not yet been approved for use in domestic or commercial appliances of this type,” he says ^[8].

For his part, John Maslen argues that the use of hydrocarbon “sounded more troublesome than it is”.

He says people overlooked the fact that a home barbecue gas cylinder can hold up to 9kg of hydrocarbon, much more than the 60 grams in his 400-litre fridges.

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Coles Gisborne CO₂/R404A supermarket refrigeration system

CASE STUDY



Coles Gisborne supermarket.



Don Griffiths outside the store



Introduction

Coles Myer Ltd is a company listed on the Dow Jones Sustainability Index. Each of its businesses is implementing an energy management plan, with the aim of reducing their overall energy consumption by 2-4% by 2010 and taking steps to introduce lower carbon solutions and offsets [1].

But the company took another very practical step a few years ago when it commissioned a 2500 square metre environmentally sustainable supermarket at Gisborne in Victoria, 50 kilometers north-west of Melbourne. The supermarket was opened in April 2005 and featured a number of sustainable design initiatives, including the use of natural refrigerants in the refrigeration systems. This supermarket would come to be known as “G1”.

“What is learned from this project will be a guide for the future design of Coles Supermarkets. The company is seeking to reduce energy demand and consumption, reduce water and waste billing, meet corporate goals and of course meet our customer expectations,” said Don Griffiths, Coles refrigeration and building services design engineer on the project just prior to its opening [2].

The project was carried out in cooperation with the Federal Department of Industry, Tourism and Resources’ Energy Efficiency Best Practice Program, which “worked in partnership with industry, consultants and other government and research agencies, to

demonstrate that significant and additional energy efficiency savings could be delivered in a range of businesses and industries” [3].

Architects McGauran Giannini Soon state the project has “developed new standards for energy performance in a supermarket, with the resulting G1 store achieving projected energy savings of over 40%. This is a significant achievement in reducing Australia’s carbon emissions having the impact of reducing emissions by nearly 1% if applied across all supermarkets” [4].

The results were such that the project won a 2005 Royal Australian Institute of Architects (RAIA) award for sustainable architecture [5] for its integration of day lighting, recycled water and various other sustainable building strategies– but it’s the refrigeration and air conditioning systems that will be of the most interest to readers of this case study.

This case study will examine how a number of aspects of the supermarket’s design work together to improve sustainability. While the refrigeration system is the major focus of this study, readers will note that factors external to the refrigeration system also need to be considered to ensure the best possible outcomes.

Building fabric

The building ‘fabric’ (walls and roof) comprises 75mm recycled concrete panels in the walls to increase the building’s thermal

mass and insulated sandwich-panel roofing. The insulation and increased thermal mass makes the store's interior less susceptible to changes in the ambient temperature outside, meaning in turn that the air conditioning system (and refrigeration systems) shouldn't have to work as hard.

Supermarkets can also have problems with temperature differentials between shopping and service areas or between the store and the air outside – warm air from outside or even inside the store itself leaking into cool rooms can create extra work for the refrigeration system, for example. The most common example of this taking place is when the doors are opened.

The G1 store has tried to minimise this problem by installing 'air locks' at both the front customer entrance to the store, and also to the loading dock at the rear of the store. The loading dock also features quick action roller shutters, and the effect of these combined with the air lock concept is to reduce the effect of temperature differentials, creating less work for the refrigeration and air conditioning systems and therefore reducing overall energy consumption.

Refrigeration system

Background

Even before Coles came to them, Frigrite Refrigeration Pty Ltd, based at Cheltenham in Victoria, was looking at ways in which natural refrigerants could be employed to replace synthetic refrigerants.

The Frigrite Alternative Refrigerant Program began in 1999 with wide-ranging aims to investigate natural refrigerants and "get ahead of the game" according to the company's national engineering manager Paul Sheahen.

Sheahen says that Frigrite, an Australian-owned company, didn't want to be "caught with its pants down". To this end, the company teamed up with Sustainability Victoria to carry out research on alternatives to the systems on the market at the time. Bitzer Australia, Danfoss Controls and the CSIRO's Energy Technology division were also brought on board for the project, sitting down to discuss ways in which they could avoid using synthetic refrigerants in preference to natural refrigerants.

"Several approaches are in play – in Europe the trend is towards using carbon dioxide (CO₂) in cascade systems (ie: in conjunction with another refrigerant)" says Sheahen.

He travelled extensively to see what was on offer overseas and investigate natural refrigerant systems, however, he believed that each system he saw had its failings so the company decided to develop its own CO₂ system.

The project resulted in the development of a pilot refrigeration cabinet suitable for supermarkets, which could be tested using R507A (a synthetic, hydrofluorocarbon or HFC refrigerant with a global warming potential of 3900 [6]) and carbon dioxide (CO₂, which has a global warming potential of just 1).

According to Sheahen, a medium temperature meat case and a freezer case were selected for the test. They were initially run using CO₂ as the refrigerant, then modified to run on R507A (a direct swap is not possible, as R507A requires the use of a polyol ester lubricant which is incompatible with CO₂ [6]). As a result, some modifications to the equipment are required before the refrigerant can be swapped).

The performance and energy consumption of the equipment was monitored for both refrigerants. Sheahen states that, when operating using CO₂, the system used less energy than when operating using R507A: 4.11kWh, as opposed to 5.24kWh. In addition to the potential environmental benefits of using a refrigerant with much lower global warming potential, the energy saving made CO₂ a very attractive option.

The Coles G1 system

The system that was eventually installed at the Coles G1 store in Gisborne was a product of this research – a "cascade" system using R507A and CO₂.

"The conventional hydrofluorocarbon refrigeration plant is replaced with a cascade hydrofluorocarbon (R507A) stage that works in conjunction with a liquid CO₂ stage to reduce fugitive emissions," says Sheahen.

The result of this is that, even though fluorocarbon refrigerants are still used, they are needed in much lower quantities when used in conjunction with CO₂. The amount of fluorocarbon refrigerant required to operate the system is 90% lower than it would be with a R507A-only system according to Sheahen (a charge of 120kg, down from around 1200kg for a similar-sized R507A only system). Lower charges mean that, even if there is a leak, less refrigerant will be lost and the CO₂ equivalent released from the leak will be much lower.

CO₂ is used for the low-temperature frozen food cases and cold rooms, and R507A is used for the remaining systems. R134a (a HFC) is used in the building's air conditioning system, and R407C (also a HFC) air conditioners are used in the food preparation areas, back rooms and staff areas [7].

Overseas experiences

The Coles G1 store is the first of its kind in Australia, and the use of natural refrigerants in supermarket applications is starting to take off overseas as well.

As early as 1993, Wal-Mart opened an "Eco-Mart" store in Kansas, USA which used ice storage as part of its refrigeration system.

Sheahen viewed a number of systems during his research overseas.

In South Africa, France and the UK there are supermarkets operating using a combination of R404A and either propylene glycol or a proprietary non-fluorocarbon heat transfer fluid. There is also a Sainsbury supermarket in the UK using a combination of hydrocarbon and proprietary non-fluorocarbon heat transfer fluids.

Sheahen says that in Denmark he came across a system using R404A in its high stage and carbon dioxide in its low stage, and it was this system that was the inspiration for the Coles G1 system.

Why CO₂?

Don Griffiths says that in an assessment of the alternative natural refrigerants, he believes CO₂ came out with a number of attributes in its favour.

"It is a natural refrigerant known and used in the past. It has a low replacement cost, is available locally and is not imported like synthetic refrigerants," he says.

He also adds the fact that CO₂ is non-toxic and non-flammable were characteristics that he viewed as "more acceptable" in a shopping centre setting.

Sheahen says that hydrocarbon refrigerants were considered early in the process, but they were eliminated based on their flammability and the need to install extra detection alarms.

While it is true that CO₂ operates at a higher pressure than most other refrigerants^[8], Sheahen says that the problem was avoided in this installation by installing more smaller pipes that effectively "spread the load".

System description

To aid efficiency, the refrigeration cabinets feature twin air screens, single row fluorescent tubes with parabolic reflectors for lighting, motorised (automated) night blinds, high-efficiency electronically commutated fan motors, low energy glass doors (on cabinets with doors) and dual pane glass on deli cases.

The fluorescent lighting configuration produces less heat than standard systems, meaning less energy is expended by the refrigeration system removing lighting-generated heat from the cabinet.

The automated night blinds are also something of an innovation. While Sheahen says that night blinds are certainly not a new concept, automating them ensures their use is not left to chance.

He says that when the blinds are controlled manually, they may not be used for days or weeks at a time because staff often forget to lower them. When the blinds are lowered, more cool air is contained within the cabinet and the system doesn't have to work as hard to maintain its temperature overnight.

Reclaimed heat from the refrigeration system is also used to provide hot water and to warm the air in front of the refrigeration cabinets, minimising the problem of customers feeling chilly as they walk past the cabinets.

All of the refrigerated display cases meet minimum energy performance standards (MEPS), and Sheahen believes that the system overall has the potential to cut power consumption by about 20 per cent.

System advantages

Sheahen states that this configuration also allows for a significant cost saving on the refrigerant itself – R507A is more expensive than CO₂ so reducing the amount of R507A required by this much provides a substantial cost benefit.

He says that there were also savings made because the system uses smaller pipes than a comparable fluorocarbon system and because efficiency gains from the whole system allowed the number of fans on each evaporator to be reduced from four to two.

Illustrating the piping example, Sheahen points out that a typical insulated copper pipe for use with R134a (another fluorocarbon refrigerant) would need to be 215mm in diameter. A pipe for the same application using ammonia (a natural refrigerant) would need to be 133mm in diameter. By contrast, the pipes required for CO₂ were only 69mm in diameter. All other things being equal, the smaller pipe will be cheaper.

Sheahen also claims that CO₂ allows for a smaller refrigeration plant which operates more quietly than an equivalent fluorocarbon system and has less vibration, and that as a refrigerant CO₂ is seven times more efficient per kilogram in this application than a synthetic refrigerant like R507A.

Conclusions

The project's backers are treating it with cautious optimism now that it is in operation, though the level of financial and energy savings couldn't be quantified at the time of writing.

"We do not want to put hard figures on it at this stage as it is early days," says Coles Myer's Paul Lang. "We are fine tuning it – when you have new technology and new equipment there are going to be teething issues and we are monitoring them and continually making improvements."

The lessons from the G1 store have already been used elsewhere though, with much of the technology developed being put to work at another Coles supermarket in Winmalee, New South Wales – indeed, Sheahen states that some of the lessons learned from doing a second system have allowed for retrofit improvements to be made to the G1 store.

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CRF (Colac Otway) Pty Ltd cascade CO₂ / ammonia freezing plant

Introduction

Lamb processing company CRF (Colac Otway) Pty Ltd is one of the biggest employers in the Western Victorian district town of Colac, providing work for more than 350 people.

It processes on average 6000 head of lamb per day, and bones out on average 3000 head of lamb per day. Its plant is a service provider for supermarket giant Coles, providing full carcasses and cuts of lamb to their distribution centres throughout Australia and to overseas customers.

But it took some time for the company to reach this position.

In the late 1990s, the owners saw a commercial opportunity for supply chain principles to be applied to meat processing and built a brand new facility using the latest design and technology principles.

In 2000, a \$9.8 million state-of-the-art processing plant was opened^[1]. But despite this great leap forward, the company was still forced to send any meat it wanted frozen to Melbourne, some 150km away.

In an effort to cut costs and increase efficiency, the company began exploring the feasibility of building a cold storage facility so it could freeze its produce on-site.

It was decided that Otway Fresh Pty Ltd, a separate entity but related company, would build a \$7 million cold storage facility to provide this service.

Otway Fresh appointed a design team which included Melbourne meat processing specialist Meateng Consultants and New Zealand company RealCold. Bendigo-based KAV Consulting also assisted in the development of the refrigeration system.

As work progressed, the team tapped into the Victorian State Government's Commercial Office Building Energy Innovation Initiative (COBEII), which provided a \$110,000 grant and support for the project^[2].

The facility, adjacent to CRF but on an independent site in Colac, freezes, chills, and stores meat products and by-products such as offal that are produced at the CRF plant. There also is provision in for products from other suppliers to be frozen at the facility on a contract basis.

The cold storage facility opened in November, 2005, and employs up to 13 people.

System overview

The central piece of equipment in the project is an automatic air blast-freezing tunnel (AABF), developed by RealCold.

The AABF installed at Otway Fresh is capable of freezing 1610 bulk packed export meat cartons with a 24-hour turn around. The design includes infrastructure to cater for an expansion should the need arise. Under the plan, the AABF could be capable of being expanded to freeze 3312 bulk packed export meat cartons, still with a 24-hour turn around^[3].

The facility also includes two forklift-loaded carton blast freezing cells, 'palletising' areas, chilled product storage and frozen product storage.

The design makes provision for a three-fold increase in the cold storage capacity and a future carton chilling facility, which could be in the form of an automatic storage and retrieval system.

Meateng consultant Steve Baum says the AABF was selected due to the varying sizes and depths of cartons handled in a single production shift. The contents of these different carton sizes range from 15kg to 25kg, which he says meant that plate freezing (an alternative freezing method) was not suitable in this case.

Use of natural refrigerants

CRF says it was keen from the outset to use natural refrigerants for the project.

The use of ammonia in cold storage and freezing applications such as the one CRF were seeking to build is common in Australia. As the team discovered, however, combining ammonia with another natural refrigerant would lead to greater efficiency and provide a number of other benefits.

After some investigation it was decided that a 'cascade' carbon dioxide (CO₂) / ammonia system could be installed. The system is the first of its kind in Australia to be built with this capacity and to be applied to an AABF, freezing cells and maintenance of cold storage, with the cool storage temperatures around the freezing point.

Baum says CO₂ was chosen because it is a non-toxic, non-flammable gas that has good thermal properties. He says another advantage is that if there were a refrigerant leak, it would not affect the quality of the meat being processed.

Furthermore, Baum states that CO₂ is an environmentally sustainable choice because of its minimal global warming potential (GWP - CO₂ has a GWP of 1, whereas synthetic refrigerants can have GWPs of up to 1500^[4]).

Using CO₂ in conjunction with ammonia instead of an ammonia-only installation was also deemed to be a better option in terms of occupational health and safety (OH&S).

While ammonia has a GWP of 0^[4] and is very efficient in a number of applications as a refrigerant, it is also toxic and leaks can be a significant OH&S hazard. In the 'cascade' configuration used for this project, however, where CO₂ is used in the staffed areas, the sections of refrigeration plant using ammonia can be isolated in the plant room and more easily contained in the event of a refrigerant leak.

Using CO₂ also gave the team access to productivity increases – traditionally, AABFs in these applications have operated on a 48-hour freezing turn around. The design team found that using CO₂ in a cascade system with ammonia gave access to higher system efficiencies which allowed the turn around time to be reduced to 24 hours, and an operating cost analysis indicated that this outcome could be achieved more economically and efficiently than using ammonia alone.

Finally, the design team noted that CO₂ systems operate under a positive pressure at all times (ie: the pressure inside the refrigeration system is greater than the atmospheric pressure outside the system), meaning that air and other potential contaminants cannot be drawn into the system^[3].

Low temperature ammonia systems operate below atmospheric pressure, potentially allowing these contaminants to be drawn into

the system. While these contaminants won't cause immediate system failure in most cases, their accumulation inside a system will increase the condensing pressure and hence the running costs if unattended.

The choice of this natural refrigerant configuration also brought some challenges though. In particular, the team needed to devote considerable effort to be devoted to finding suitable materials for the system, as the majority of commercially available materials were not suited to applications of below -40°C, and there were some cost considerations. These challenges are discussed below.

Costs and system configuration

Using CO₂ in combination with ammonia as opposed to an ammonia-only system did have an effect on the cost of the system, and various factors had to be weighed up during the design process.

One issue was with the cascade condenser, a component required to make the CO₂ / ammonia design function. The design team says that the condenser required for the CO₂ / ammonia design was more expensive than an equivalent ammonia-only model, however, cost savings in other areas of the project cancelled out the extra cost.

The condenser eventually chosen was a plate and shell design with it high performing capacity made by Vahterus, a Swedish company with a track record in CO₂ condensing applications^[3].

CO₂ systems also operate at a higher pressure than ammonia systems, and this high pressure means that the vessels containing the CO₂ need to be designed for these higher pressures. As a result, they cost more than the vessels that would be required for an ammonia system of the same capacity.

According to the design team, the capital cost of a carton-freezing tunnel such as the one used at Otway Fresh is fairly constant for any given number of carton spaces. Therefore, the comparative capital cost per carton frozen is dependent on the number of cartons frozen per day^[3].

For example; a freezing tunnel costing say \$1 million and holding 5000 cartons has an effective capital cost of \$200 per carton when freezing on a 24-hour cycle. The cost blows out to \$400 when operating on a 48-hour cycle.

Realcold's Brian Edwards cautions that a 10,000-carton tunnel does not cost twice as much as a 5000 carton tunnel though. "Care must be exercised in how the various costs are evaluated and compared," he says.

A detailed study was undertaken to compare the capital cost of a AABF CO₂ system on a 24-hour turn around with that for a 48-hour turn around in a conventional tunnel and ammonia refrigeration system.

There were four options considered:

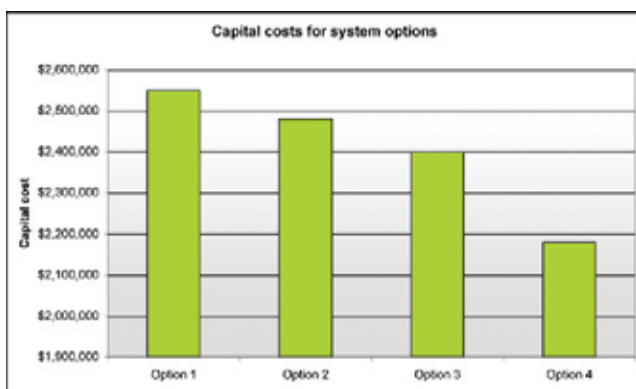
OPTION 1: A 48-hour freeze tunnel with a two-stage plant room at a total cost of \$2.55 million. Included in this figure was the cost of building the AABF with a capacity to freeze 3300 cartons over 48 hours, estimated at \$1.2 million, and the cost of the plant room equipment was \$390,000. The plant in this configuration would use 402 kW of power.

OPTION 2: A 48-hour freeze tunnel with economised one-stage plant room at a total cost of \$2.48 million. The plant room equipment would cost \$320,000 and the AABF \$1.2 million. Power use was estimated at 452 kW.

OPTION 3: A 24-hour freeze tunnel with two-stage ammonia plant room with a total cost of \$2.4 million. The plant room equipment was put at \$450,000 and the AABF at \$900,000. Energy consumption was estimated at 436 kW.

OPTION 4: A 24-hour freeze tunnel with a cascade CO₂ / ammonia plant room at a total cost of \$2.18 million. The cost of the plant room was put at \$450,000 and the AABF at \$900,000. Energy consumption was estimated at 401 kW.

Options 1 and 3 also included a glycol system, the cost of which was estimated at \$60,000. Cooling equipment inside the cold rooms common to all four options was priced at \$200,000.



Comparison of system costs

The design team drew the following conclusions^[3]:

1. The cascade CO₂ / ammonia system (Option 4) was estimated to be \$370,000 lower capital cost than the 'conventional' solution of 48-hour carton freezing and two-stage ammonia plant room (Option 1).
2. In this instance, the power drawn by the system's compressors at full load was similar between Options 1 and 4. In other cases, however, a 48-hour freezing cycle using a two stage ammonia plant may consume less energy than a 24 hour freezing cycle in CO₂ / ammonia cascade configuration.
3. The CO₂ / ammonia cascade system (Option 4) running at -50°C had a much lower (around 20%) compressor drawn power than the two-stage ammonia system. This came about because the high efficiency reciprocating compressors being used on both stages of the cascade option.

The ammonia option was based on screw compressors and those on the high stage were relatively small and had lower efficiencies, especially at part load conditions. In other instances the reverse could be true were small screw compressors required to operate on the CO₂ system and larger, more efficient screw compressors used on the alternate ammonia system.

Edwards cautions that on this basis it was important to make full evaluations of each particular application. What is most efficient for this application may not necessarily work as well for other sites.

In summary, it was found that 24 hour freezing using a CO₂ / ammonia cascade system consumed less energy in this case than 24 hour freezing using a two-stage ammonia plant, but more energy than a 48 hour freezing cycle using a two stage ammonia plant.

Edwards also concluded that using CO₂ would allow for a cost saving on pipework, as CO₂ needs small pipes than an ammonia-only system and because copper can be used to make CO₂ pipes for -50°C systems.

The savings in capital costs between 24-hour and 48-hour carton freezing tunnels exceeded the increased cost of the CO₂ / ammonia cascade refrigeration plant room when compared with the cost of a conventional ammonia plant room.

Therefore, 24-hour freezing with cascade CO₂ / ammonia was shown to be a lower capital cost solution than 48-hour freezing with ammonia.

Further, 24-hour freezing with a cascade CO₂ system was proven to be a lower cost than 24-hour freezing with ammonia, as using ammonia only required compressors that were eight times larger than the CO₂ option to operate at -50°C.

The system also provides versatility which can allow for further cost savings in some circumstances.

The AABF as installed can be set to operate on a 48-hour cycle rather than a 24-hour cycle, which uses less energy than the 24-hour cycle. This means that the system operator has the ability to extend the freeze time in periods of low production and reduce running costs.

Safety

While ammonia has long been used as a refrigerant, its toxicity is often a stumbling block precluding it from widespread use in areas where a lot of staff are working.

Australian Standard AS/NZS 1677.2 *Refrigerating systems Part 2: safety requirements for fixed applications* [5] dictates various safety precautions that need to be put in place for an ammonia-only system in an application such as the CRF one, including limits on personnel density and the amount of refrigerant that the system can hold.

Theoretically, ammonia could have been used in several rooms at the Otway Fresh facility, however, the size of the rooms and the number of personnel expected to work in them would have exceeded the safety requirements set out by the standard.

Otway Fresh wanted to take a strong stand on OH&S, and as a result tenders for the project dictated that no direct ammonia would be used in the project's occupied areas.

The tender noted that there had been "examples of large ammonia leakages reported in the Australian meat industry and it seems a prudent move to avoid the use of ammonia in the field if there was a cost-effective alternative available."

In addition to the personnel risks, if ammonia leaked in an area containing meat products, the products would be contaminated and would have to be disposed of. A CO₂ leak, on the other hand, would not result in product contamination.

Additionally, the tender suggested an alternative such as glycol, which is not harmful to people, should be used. In the final design, CO₂ was used instead of glycol.

The use of CO₂ also carries risks – while it is non-toxic and non-flammable, CO₂ is heavier than air and displaces oxygen in a room, so a large enough leak in a confined space can cause suffocation. It is also odourless (unlike ammonia) so detectors need to be installed to warn staff in the event of a leak.

The Otway Fresh plant at Colac has had leak detectors installed in all areas to ensure early detection occurs, according to Baum.

Risk minimisation

The use of CO₂ at Otway Fresh has allowed the amount of ammonia in the system to be minimised. The design team estimates that an ammonia-only system would have had an ammonia charge about 90% higher than the CO₂ cascade charge. The cascade system adopted also allows the ammonia charge to be contained within the plant room at a safer distance from personnel.

The plate and shell type condenser chosen for the system also helps to minimise the ammonia charge as it has an extremely high performance capacity per unit volume, meaning the charge of ammonia – used to condense the CO₂ – is kept to a minimum.

Baum points out that if CO₂ had not been used, the charge of ammonia on the site could have been as high as six tonnes.

Consultant Klaas Visser suggests that OH&S is one of the top three issues facing the food processing industry, hence the shift away from ammonia in staffed areas.

"The ready acceptance of CO₂ / ammonia cascade systems was mainly driven by the occupational health and safety issues, which is the number three issue facing the food processing industries in general," he says^[6].

Conclusion

CO₂ has offered CRF and Otway Fresh the ability to economically freeze cartons in 24 hours using air blast systems.

The capital costs were proven to be lower than an equivalent ammonia system, and the operating costs are expected to be better than an ammonia system operating on a 24 hour cycle.

CO₂ is not toxic, will have no effect on the product in the event of a leak, and has been found to be safer to use in occupied spaces than ammonia.

The 24-hour freezing cycle offered by the CO₂ / ammonia cascade system has also allowed stock holding and inventory levels to be reduced.

At the time of writing, it is early days but the team believe the plant is on track.

"It certainly has attracted some interest," says Baum says.

Realcold states it has fielded inquiries from other meat works interested in the project.

The carton freezers and cold store will be monitored and tested during operation.

There have also been other positive outcomes - in announcing the \$110,000 assistance grant, State Environment Minister John Thwaites said the choice of CO₂ would cut greenhouse pollution by as much as 900 tonnes each year^[2].

This, he suggested, would be the equivalent of removing 210 cars from Colac's roads or save enough energy to power almost 40 homes for the year in the town.

While the system won't be right for all applications, it is certainly worth evaluating for large freezing and refrigeration projects.

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Acknowledgements

The authors would like to gratefully acknowledge the input of the following people to this case study:

- Jack Barclay, Mark Westgarth and Laura Sexton (CRF)
- Brian Edwards (Realcold)
- Merv Jaensch and Steven Baum (Meateng)
- Klaas Visser (KAV Consulting)

Other resources



Air Conditioning and Refrigeration Institute

— www.ari.org

The Air Conditioning and Refrigeration Institute (ARI) is a US-based organisation representing manufacturers of air conditioning and commercial refrigeration equipment. Its website provides information on product testing and international refrigeration equipment standards.

Australian Institute of Refrigeration, Air Conditioning and Heating

— www.airah.org.au

The Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) provides training and technical information for the refrigeration and air conditioning industry. Its website contains information on ammonia refrigeration training programs and articles on natural refrigerants from the institute's magazine, EcoLibrium®.

Department of Environment and Water Resources

— www.environment.gov.au

The Australian Government Department of the Environment and Water Resources (formerly the Department of the Environment and Heritage) develops and implements national policy, programs and legislation to protect and conserve Australia's natural environment and cultural heritage.

International Institute of Ammonia Refrigeration

— www.iiar.org

The International Institute of Ammonia Refrigeration (IIAR) is a US-based organisation representing users of ammonia refrigerant. Its website offers information on conferences held by IIAR, safety and technical information and general information on the use of ammonia as a refrigerant.

International Institute of Refrigeration

— www.iifir.org

The International Institute of Refrigeration (IIR) is an international, intergovernmental organisation enabling pooling of scientific and industrial know-how in all refrigeration fields. Its website offers explanatory notes on various refrigeration technologies (including natural refrigerants) as well as access to research databases for more in-depth information.

Natural Refrigerants Transition Board

— www.nrtb.org.au

The Natural Refrigerants Transition Board (NRTB) is an Australian group established to "assist in the wider acceptance of natural refrigerants in the community." Its website provides information on various information sessions and programs run by the organisation, as well as links to further reading.

Refrigerants, Naturally

— www.refrigerantsnaturally.com

Refrigerants, Naturally is an initiative supported by the United Nations Environment Programme (UNEP) and Greenpeace for large businesses, including McDonalds, Coca-Cola, Unilever, PepsiCo, Ikea and Carlsberg, to implement fluorocarbon-free refrigeration systems.

Standards Australia

— www.standards.org.au

Standards Australia is the body responsible for producing and publishing Australian Standards. Its website provides information on the standards writing process, opportunities to comment on draft standards, and opportunities to purchase relevant Australian Standards.

Workplace Safety Australia

— www.worksafe.com.au

Workplace Safety Australia provides advice and information to Australian companies on occupational health and safety issues and strategies. Its website provides various newsletters, publications and question and answer forums (note: subscription may be required to access some of these services).

Note: all website links were correct at the time of publishing (April 2007)



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with funding from the Department of Environment and Water Resources