The changing face of refrigeration

Judith Evans traces developments in refrigeration technology to the present time when energy efficiency and reduced environmental impact are increasingly important drivers

The early days

Refrigeration is a vital part of almost everyone's life in the developed world. Few people can survive without their domestic refrigerators to keep food safe and cool, their air conditioned cars and offices (and increasingly, their air conditioned homes). The whole food chain is underpinned by refrigeration from primary food processing through storage, transport and retail.

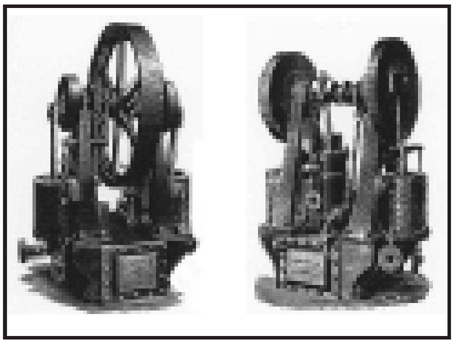

Figure 1. Air cycle machinery used on board ships in the late 1800s.

However, 200 years ago keeping food cold was restricted to totally natural means. Either ground cooled cellars or pantries were used to keep food chilled or food was stored on ice. Ice was either collected from icebergs or was made in ice ponds where water was frozen using radiant cooling at night. The ice was then harvested and stored in icehouses; today, many of these underground houses can still be seen in the grounds of Britain's stately homes (1).

Although refrigeration systems using a working fluid or 'refrigerant' were invented in the early 1800s, refrigeration only began to be used for food transport in the late 1880s. At that time, ships began to transport food using large air cycle systems (Fig. 1).

With the introduction of new refrigerants, air cycle was no longer a competitive option. Refrigerants such as carbon dioxide, sulphur dioxide and ammonia were popular alternative refrigerants for a while until, in 1928, Thomas Midgley discovered chlorofluorocarbons (CFCs); these were to dominate refrigeration for the major part of the 21st century. They were considered wonder chemicals that were efficient, cheap, non-flammable, non-toxic and allowed refrigeration to be available to everyone. In the 1930s, food began to be frozen by Clarence Birdseye and the food industry never looked back.

CFCs

Although CFCs were hailed as the wonder chemicals of their day and were even considered to be environmentally 'safe', their supremacy as suitable refrigerants has been attacked in the last 25 years. In 1974, Molina and Rowland (2) published the first paper linking CFCs and the destruction of the ozone layer. It took until 1989 and the realisation of the potential global catastrophe for nations to agree a phase out of CFCs through the Montreal Protocol.

Environmental issues

The phase out of the widely-used CFCs obviously had, and has continued to have, a major impact on the refrigeration and food industry. The intermediate hydrochlorofluorocarbons (HCFC) compounds developed to replace CFCs are now being phased out as these still have some ozone depletion potential (ODP). It is therefore important when selecting a refrigerant that it has long-term sustainability and can be serviced and maintained for the proposed life of the equipment.

As less ODP gases are released, the emphasis transferred from ozone depletion to global warming caused by the release of greenhouse gases such as carbon dioxide, methane, CFCs, HCFCs and halons. The Kyoto Protocol agreed in 1997 was aimed at reducing emissions and has been the driving force behind the UK government's aim to reduce greenhouse emissions by 12.5%, based on 1990 or 1995 levels, in the years 2008-2012 (3). Refrigerants such as the hydrofluorocarbon (HFC) chemicals or F-gases that were developed to replace CFCs and HCFCs have low ODP and mainly low global warming potential (GWP). They are however still being targeted in some Scandinavian countries as possible chemicals to ban. The Europe-wide introduction of the F-gas regulations that will probably come into force in 2006, will add an additional level of management of refrigeration plant operating on HFCs to ensure compliance with the legislation.

Although leakage of HFC refrigerants is a factor in GWP, the major source of global warming can be attributed to the energy used by any refrigeration system and the carbon dioxide released during production of that energy. This is applicable to any refrigeration system using any refrigerant. With the recent increases in energy costs, this has placed greater emphasis on energy efficiency than ever before.

Alternative options

Due to the uncertainties surrounding the long-term sustainability of HFCs, many companies have begun looking at alternative refrigeration options. Ammonia is a refrigerant that has begun to increase in popularity. Although never totally out of favour due to its efficiency, ammonia has deservedly seen a revival in recent years and is an efficient alternative for food processing. Carbon dioxide is also slowly beginning to increase in popularity. Components suitable for use at the high operating pressures encountered with carbon dioxide are increasingly becoming available and this has resulted in more companies offering carbon dioxide as a refrigerant for food processing. Pioneering projects by companies such as Star Refrigeration have shown that refrigerants with zero ODP can be effective and efficient.

Refrigerants such as hydrocarbons (zero

ODP and minimal GWP) have also been successful in certain markets. The majority of domestic refrigerators manufactured in Europe now operate on isobutane (R600a). Although not suitable for large systems (due to flammability), hydrocarbons have been shown to be efficient refrigerants and have been widely accepted in all countries bar the USA. Increasingly, hydrocarbons are becoming more popular for commercial and catering cabinets as larger companies such as McDonalds have become more environmentally conscious (4).

Air, one of the first refrigerants used to chill or freeze food, could potentially be an option. Air has a number of attractions; as a refrigerant it is environmentally benign, and apart from the energy used to operate the refrigeration system, has zero ODP or GWP. The large and inefficient equipment that brought about its demise at the beginning of the 1900s, can now be replaced with high speed, high efficiency turbo machinery that is compact and extremely reliable. One of the major advantages of air as a refrigerant is its ability to operate at extremely low temperatures that are comparable to cryogens. Therefore, very fast freezing of food is a possibility. For small food items such as carrots, prawns, surimi or squid it is predicted that freezing time to –20°C in an air cycle fluidised bed freezer operating at –100°C would be four times faster than conventional freezing in air at –30°C (Fig. 2). Although air has many advantages it will only outperform one of the most efficient refrigerants, ammonia, in terms of energy consumption at temperatures below –50°C and therefore it is best suited to food freezing (5). Air does however, have one other valuable feature; heat recovery. If the cooking and cooling process could be coupled together, energy savings of approximately 30% could be achieved. This level of energy savings would have a huge impact on the food industry (estimated at £676 million per year) and is the basis of a project funded by Defra LINK that will soon begin at FRPERC, University of Bristol.

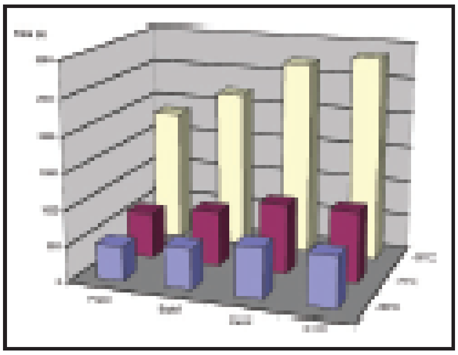

Figure 2. Predicted freezing times from 15°C to –20°C in air at –100, –55 and –30°C.

Looking further ahead

Other long-term options may also emerge in the next 10-15 years. Several novel technologies have potential as chilling or freezing technologies of the future. Of these, acoustic Stirling and magnetic refrigeration have mainly been developed in the USA. Work is just beginning to commercialise small (domestic/small commercial) acoustic

Stirling systems at Pennsylvania State University and small (domestic) magnetic refrigerators at Ames Laboratory. Other technologies, such as thermionic and magnetic resonance freezing, are still only small scale and are only likely to be suitable for commercial chilling or freezing in the long-term.

Due to greater interest in energy efficiency, sustainable technologies have begun to receive interest. TNO in the Netherlands has recently launched their 'Sustainable Cooling Initiative' (6) to bring together and showcase sustainable refrigeration technologies. Technologies such as solar energy, ground source cooling, radiative cooling, heat pipes and thermosyphons are all 'free' sources of cooling that could be developed. The major downside of these new technologies is initial cost and availability of economically-priced equipment and this is where many of the future challenges lie. Can engineers and researchers design new systems that are efficient and persuade equipment manufacturers that there is a large enough market for them to develop mass-market components? Can food industry buyers look beyond the initial cost of equipment and make purchases based on lifetime costs? There is an indication that, driven by energy costs, environmental lobbying and legislation, many companies are beginning to seriously consider the refrigerants used in chilling or freezing equipment and, if these drivers remain, this trend is likely to continue.

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Judith Evans is a Research Fellow at the Food Refrigeration and Process Engineering Research Centre (FRPERC), University of Bristol, Churchill Building, Langford, North Somerset BS40 5DU, UK.
Tel.: +44(0)117 928 9300
Email: j.a.evans@bristol.ac.uk
Web: www.frperc.bris.ac.uk.