Alternative Refrigerants – Part 1  
Future and Current Options

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Overview

Part 1 of this two-part editorial article looks into the current usage of refrigerants in the many varied sectors of the refrigeration and air-conditioning sector, provides reasoning why mounting pressure on synthetic refrigerants will push the industry towards more environmentally benign alternatives, and provides a practical outlook on the alternatives available and the challenges that our industry faces in the transition.

Nomenclature:
The following common acronyms are used in this paper:
CFCs – ChloroFluoroCarbon refrigerants
CO2 – Carbon Dioxide, also known as R744
DX – direct expansion
HCS – Hydrocarbon refrigerants
HCFCs – HydroChloroFluoCarbon refrigerants
HFCs – HydroFluoCarbon refrigerants
IPCC – International Panel for Climate Change
GWP – Global warming potential, relative to Carbon Dioxide, CO2
MVAC – Motor Vehicle Air Conditioning
NH3 – Ammonia, also known as R717
ODP – Ozone Depleting Potential, relative to R11

The status quo – a sectorial view:
The 2007 report released by the IPCC analysed refrigerant usage across the globe and the industry, and developed insightful statistics on the refrigerant leakage rate in the various sectors. Typical average annual leakage rate, as percentage of total system charge are reported as follows:

- Commercial refrigeration: 15% to 30%
- Industrial refrigeration: 10% to 25%
- Transport: 25%
- Air Conditioning and Heat Pumps: 18%
- Chillers: 10% to 15%
- Motor Vehicle Air Conditioning: 10%

The significance of these numbers lies in the direct impact of the refrigerant on the environment, as opposed to the impact of the energy consumption of the systems (indirect impact). The commonly repeated statement by synthetic refrigerant suppliers and their supporting organisations, is that the environmental impact due to refrigerant release represents "less than 10%" of the indirect impact. The enormity of this generalisation, over the full range of sectors, refrigerants and countries, should encourage every thoughtful reader to dig deeper.

The sad reality is that for Australian mainland conditions (with a carbon emission of around 0.9 kg CO2/kWh) the actual percentage of the direct impact is anywhere between 5% and 70%, depending on refrigerant and sector. In New Zealand and Tasmania, where carbon emissions are less than 0.3kg CO2/kWh, these numbers blow out to between 13% and 88%!!! Refrigerant release quickly becomes the dominant environmental impact from a RAC application.

Lets look at the various sectors, one by one:

A) Fluid chillers for commercial and industrial applications:
B) Commercial and large domestic air conditioning
C) Small domestic air conditioning
D) Stand-alone refrigeration – commercial and domestic
E) Industrial and marine refrigeration
F) Transport refrigeration
G) Motor vehicle air conditioning
H) Commercial refrigeration

Fluid chillers for commercial and industrial applications (IPCC: 10-15% leakage rates):

New air conditioning applications are dominated by HFCs, including R134a, R407c and lately R410a. In centrifugal chillers R123, which is an HCFC and hence ozone depleting, is still widely used. A very large base of equipment using R22 (HCFC) as well as R12 and R11 (CFCs, now banned for new equipment under the Montréal Protocol, is still in widespread use. New R22 equipment is still being installed in spite of the imminent phase-out of that gas, simply due the low capital cost of R22 equipment.

In this sector alternative low GWP refrigerant are little used, although their use is rapidly growing.

Commercial and large domestic air conditioning

Domestic air conditioning: (IPCC: 18% leakage rate)

R22 dominates this sector in Australia and the USA, in spite of impending phase out of the HCFC refrigerant. R410a is making inroads into the market for smaller systems in particular, whilst R134a is more widely used for larger and roof-top packages.

Low GWP alternative systems using R290 (Propane) are available in Europe, and recently also in Australia. The major problems in this sector relate to poor installation and servicing practices especially in the domestic sector, with venting of refrigerant still widespread in spite of stringent legislation (but lax enforcement, certainly in Australia)

Stand-alone refrigeration – commercial and domestic

HFC refrigerant dominate this sector, with R134a commonly used for medium temperature cabinets, and R404a for freezer cabinets.

In Europe the use of low GWP hydrocarbon refrigerants is widespread and dominates domestic refrigeration. R600a and R290 are the main refrigerants used here. Unilever has standardized on hydrocarbon refrigerants for all its cabinets, and is currently involved in a world-wide roll-out of cabinets using these gases.

Coca Cola on the other hand has standardized on the use of CO2 (R744) for its drink coolers, and is similarly in the process of rolling these out intentionally.

Due to the small refrigerant charges in these systems (generally <1kg / unit), the direct impact of refrigerant is small with the direct impact generally <5% for R134a cabinets (but higher for R404a cabinets).

Industrial and marine refrigeration (IPCC: 10-15% leakage rate)

R22 flooded systems and R22 industrial chillers are still widely used for land-based systems, and R22 is the dominant refrigerant for marine applications.

Ammonia is used virtually exclusively for all new land-based systems, often in combination with secondary refrigerants such as water based blends of Propylene Glycol or Ethylene Glycol.

R404a/R507 systems still used for some smaller DX systems, such as smaller cold stores. Here leakage rates are similar to commercial refrigeration applications. CO2/R134a and CO2/R404a cascade systems are being used as an improved interim solution. First CO2-only systems (also called “transcritical CO2”) are planned.
CO2/NH3 cascade systems are becoming mainstream for industrial freezer applications, and are gaining a foothold in marine applications.

Transport refrigeration
Motor vehicle air conditioning

Truck refrigeration systems commonly use R404a refrigerant, whilst the most widely used refrigerant for bus and car air conditioning systems remains R134a. R134a appears doomed as long term solution for MVAC applications, after the European ban on this gas for new models. Hydrocarbons are widely used in the Australian retrofit industry due to their low cost and relative performance benefits, especially in the car A/C market. No OEM has as yet embraced HC refrigerants, and the verdict is out as to whether the Australian auto market will follow the European lead to embrace CO2 as preferred refrigerant for MVAC applications, or follow the push by Honeywell/Dupont to have their mildly flammable alternative HFC 1234yf anointed as the heir of R134a.

Commercial refrigeration

Commercial refrigeration systems cover a wide range of applications, including supermarkets, corner stores, pubs clubs, hotels, restaurants and the local butcher shop. Systems range from small air-cooled units with remote evaporators to multiple compressor rack systems with water cooled or remote air-cooled condensers. One thing most commercial refrigeration systems have in common, are long suction and liquid lines, and DX evaporators often far away from the compressors. Commercial refrigeration systems are known for the very high leakage rates (generally in the order of 20-25% for well maintained systems), and also for the large refrigerant quantities used in the systems. R22 and R404a/R507 dominate the market, although R22 is on the decline. CO2 refrigerant is making its first inroads into the commercial refrigeration market, a trend that is expected to accelerate in coming years.

High GWP refrigerant – why will they go?

As a quick reminder to the reader the following chart provides an overview of the common know refrigerants and their status as CFC, HCFC, HFC or Halogen Free (also known as “natural”). CFC refrigerants are all currently banned for new systems in accordance with the Montral Protocol, to which both Australia and New Zealand are signatories. Hence new CFC systems cannot be built, nor may CFC refrigerants be manufactured or imported. However, existing CFC-based systems may still continue to be operated.
As a further reminder, it is useful to look at the phase-out schedule for HCFCs (this includes R22 and R123). Australia and New Zealand are on the same trajectory as the USA, requiring a full phase-out by 2020, but substantial reductions on the way. This phase-out effectively puts notice on R22, and should serve to discourage all but the most short-sighted users from opting for R22 or R123 at this point in time.

(Ref: “Refrigerants for commercial applications – Copeland/Emerson August 2007)
This leaves only HFC and Halogen free refrigerants as possible long-term options. In considering these options, it is vital to consider the extremely high GWP values of commonly used HFC refrigerants, in comparison to halogen free natural refrigerants such as CO2 and NH3, see table below.

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>100yr GWP</th>
<th>20 yr GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>R717 (Ammonia)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>R744 (CO2)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>R290 (Propane)</td>
<td>&lt;20</td>
<td>&lt;20</td>
</tr>
<tr>
<td>R404a</td>
<td>3,862</td>
<td>5,651</td>
</tr>
<tr>
<td>R134a</td>
<td>1,410</td>
<td>3,590</td>
</tr>
<tr>
<td>R410a</td>
<td>2,060</td>
<td>4,095</td>
</tr>
<tr>
<td>R407c</td>
<td>1,749</td>
<td>3,869</td>
</tr>
<tr>
<td>R417a</td>
<td>2,312</td>
<td>4,577</td>
</tr>
<tr>
<td>R22</td>
<td>1,780</td>
<td>4,850</td>
</tr>
<tr>
<td>R12</td>
<td>10,720</td>
<td>10,340</td>
</tr>
</tbody>
</table>

All commonly used HFCs have 100year GWP values of more than 1000 times that of CO2. To quote the statistics used by Ted Garland of Verisae in October 2007:

“One 100 pound cylinder of R404a leaked to the atmosphere equals:
- 27 Chevy Suburbans Driving 12,000 miles each, or
- 28 acres of forest”

A similarly alarming statistic can be delivered by applying known and verified leakage data from Australian Coles Supermarkets:
The leakage of refrigerant from refrigeration systems alone (not considering any indirect effects due to power consumption, or any leakage from A/C systems) from each Coles or BiLo store is equivalent to 140 cars on the road.

Taking the IPCC statistic of 18% average leakage rate for fluid chillers as a maximum value, and assuming 10% leakage rate for a typical 1,500kW chiller, the global warming impact of the annual direct refrigerant leakage equates to the indirect effect from one month of operation at full load. Put differently, leakage of refrigerant in this sector equates to an increase in power consumption of 20-40%.

Conclusions:

The above analysis leads the reasonable reader to the following conclusions only:

- The use of high GWP HFC refrigerants is NOT sustainable.
- The industry will in time convert to low GWP alternative fluids
- Corporate Social Responsibility (CSR) and emissions trading will impact heavily on high GWP gases, further driving industry to see low GWP alternatives.

**Future alternatives – an overview**

History always has a tendency to repeat itself, and the refrigeration industry is a prime candidate. The following graphic (compliments of Alex Pachai, JCI, June 2007) is very illustrative of this point.

The very first refrigeration systems ever built used natural refrigerants such as NH$_3$, HCs and CO$_2$. After the invention of CFCs in 1929, the industry all but forgot these original gases, but the Montreal Protocol in 1987 changed all of that, forcing the chemicals companies to invent the alternative HFCs gases. These gases are now regulated by the 1997 Kyoto Protocol, and increasing pressure from subsequent regulations and emissions trading systems will force the industry to go back to the same roots that it started from. However, this time
engineers will be far better prepared to deal with the technical challenges of toxicity and flammability posed by these environmentally benign gases, and their public acceptance will inevitably grow as environmental awareness grows.

R22 replacements?

With HCFC refrigerants including R22 rapidly on the way out of favour, a common question is what to replace it with? Without exception, all the synthetic refrigerants listed in the table above have extremely high 100 year GWP values. Considering that most HFCs gases have an atmospheric lifetime of less than 20 years, the use of the 20 year GWP is in fact more realistic, and may very well be adopted in future to measure the impact of HFCs and to establish their carbon-equivalent cost in an emissions trading system. A quick look at the 20 year GWP values for every one of the R22 HFC-replacements presented to the industry by the chemical industry quickly lead to the conclusion that none of these options hold any long-term potential, except for entirely hermetically sealed applications.

Hence, once again we conclude that our long term options for R22 replacement are restricted to halogen free refrigerants. This would include:

- natural refrigerants such as Ammonia, CO2 and Hydrocarbons or blends of these gases, such as R723
- low GWP synthetic refrigerants, such as HFO 1234yf (available after 2009)

**Alternative Refrigerants – sector by sector**

Where could the various alternative options discussed above find application? The list below provides some perspective:

- Fluid chillers – A/C + industrial
  - Ammonia, R723 and R134a in charge-minimized systems
  - Transcritical CO2 heat pumps for large scale heating/cooling
- Commercial and large domestic A/C
  - Low GWP synthetics and transcritical CO2
- Small domestic A/C
  - Low GWP synthetics and Hydrocarbons
- Stand-alone refrigeration – commercial and domestic
  - Low GWP synthetics, Hydrocarbons and transcritical CO2
- Industrial and marine refrigeration
  - Ammonia and ammonia/CO2 cascades
- Transport refrigeration
  - Low GWP synthetics and Hydrocarbons
- Motor vehicle and bus A/C
  - Low GWP synthetics, Hydrocarbons and transcritical CO2
- Commercial refrigeration
  - Large systems: Low GWP synthetics, R723 + cascade CO2, and transcritical CO2
  - Small systems: Low GWP synthetics, Hydrocarbons and transcritical CO2

**Challenges to our industry:**

In dealing with the inevitable change from the current wide use of HCFC and HFC refrigerants to the use of the alternatives described in this editorial, our industry faces a range of challenges that it will need to overcome:

Technical challenges:
- Use flammable + toxic refrigerants safely
- Apply very high pressure refrigerants
- Understand transcritical CO2 systems
Logistical/political
- Train and re-train technicians in servicing systems containing alternative refrigerants
- Re-educate our consultants to understand the building requirements associated with alternative refrigerant use.
- Review our codes and standards to achieve world-best standards
- Get the politicians and public to understand the need for change

For further information, feel free to contact the Green Cooling Council on info@greencoolingcouncil.org.au