Advantages Of Using Hydrocarbon, Green, Refrigerants In Laboratory Coolers / Freezers

Currently used refrigerants in laboratory freezers and/or coolers are mostly of the fluorocarbon type. These refrigerants do contribute, when emitted to the atmosphere, to the greenhouse effect. Therefore, these chemical refrigerants are included in the Kyoto Protocol that is linked to the United Nations Framework Convention on Climate Change. It is clear that there is pressure on the use or emission of these refrigerants, which means that limitations can be expected in future. This may pose problems for existing freezers at the end of life or during servicing. As an alternative it is possible to apply hydrocarbon refrigerants, which are generally excellent refrigerants with favourable properties and contribute very little to global warming. If well designed, in many cases an energy saving can be expected which reduces the environmental impact further, by reducing the CO_2 emission related to the electricity generation needed to drive the product. The drawback however, is that hydrocarbon refrigerants are flammable and adequate measures are needed to design safe products. Experience in other application areas, such as domestic and commercial refrigeration, has shown that this is well feasible.

"The lessons which can be learned by the earlier phase out of CFCs is that equipment operating with such refrigerants can in general still be used through its lifetime if no servicing of the refrigeration circuit itself is needed"

Author Details:

M. Janssen & J. Wijnstekers
Re/genT BV, Lagedijk 22,
5705BZ Helmond, The Netherlands
martien.janssen@re-gent.nl

INTRODUCTION

Laboratory freezers and/or coolers generally apply a vapour compression technique to generate a cold environment for storage of various goods. The basic circuit behind this cooling process always contains a compressor, condenser and evaporator (*see Figure 1*). In this circuit heat is released from the condenser to the ambient and heat is absorbed by the evaporator, which is typically placed inside the cabinet to be cooled. The compressor is needed to circulate a refrigerant and to raise the refrigerant pressure from the evaporator to the condenser level.

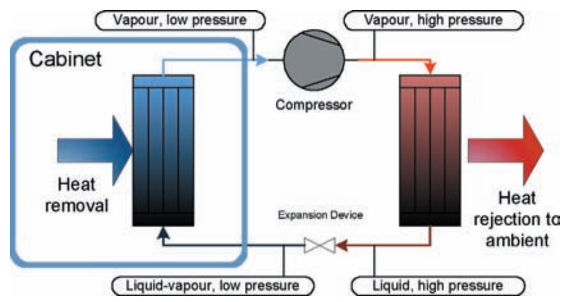

Figure 1. Schematic representation of a vapour compression cooling system.

Depending on the application, variations to the system described above may exist. For example, to achieve very low temperatures, it is possible to arrange two vapour compression systems in such a way that the condenser of the low temperature circuit delivers its heat to the evaporator of the high temperature circuit (this is a so called cascade system). Different refrigerants are typically used in each of the two circuits due to the very different temperature conditions in the circuits. It is also possible to run low temperature systems with a single compressor and use a mixture of refrigerants in a so-called auto-cascade system arrangement. Such system requires a number of internal heat exchangers.

In any case the selection of a proper refrigerant is based on a number of design criteria. However, since the mid eighties of last century, also a number of environmental criteria's have been added to this selection process. This will be described in the second section of this paper where both ozone depletion created by the earlier refrigerants and greenhouse effects of replacement refrigerants is discussed. Currently there is legislation under development that will also restrict the use of refrigerants with a substantial global warming impact.

During recent years the use of hydrocarbons as refrigerant has gained interests. Such refrigerants have actually been in use in domestic refrigeration systems as far back as 1920-1930, where they got replaced with non-flammable, but ozone-depleting refrigerants. Being faced today with environmental problems of the current refrigerants and having possibilities to design, construct and maintain, safe systems applying flammable refrigerants, the interest in this solution is renewed. The properties and use of hydrocarbons will shortly be discussed in section 3.

As the main concern of applying hydrocarbons relates to the safety aspects, it is evident that products applying this technology must be carefully designed. To assist this process, to date relevant safety standards have been developed, or are in progress in certain application areas. In general complying with a safety standard addressing the use of flammable refrigerants will minimise the risks associated with the production, use and destruction of the product. Section 4 addresses the relevant standards and its application to a typical laboratory freezer, resulting in a safe system using natural refrigerants.

Apart from the flammability, hydrocarbon refrigerants can be classified as excellent refrigerants, due to favourable thermodynamic properties and heat transfer characteristics. This often leads to a reduction in energy consumption of the application, which leads to a reduction in the global warming contribution related to the product. As the refrigerant used can also have a direct contribution to the global warming when emitted at the end of life (or due to a leakage) it is possible to add these two effects in the so called TEWI factor (total equivalent warming impact). This issue is addressed in section 5. Finally the conclusions will summarise the steps needed to design a safe product using HCs and the environmental advantages associated with this choice of refrigerant.

REFRIGERANT SELECTION, HISTORY AND FUTURE PROSPECTS

Until the end of the eighties, generally chloro-fluorocarbon (CFC) refrigerants were employed in laboratory coolers. Due to the discovery of their damaging impact on the ozone-layer, this class of refrigerants became controlled under the UN Montreal Protocol and was effectively banned in the following decade. The replacement refrigerants are primarily of the hydro-fluorocarbon (HFC) type, where HFC-134a, R-404A and R508B are known examples . These refrigerants have in common that they have a relatively strong global warming potential (GWP), which is generally expressed as a ratio number to the generally known greenhouse gas CO2. For example, HFC-134a has a GWP of 1430, R-404A of 3900 and R-508B a value as high as 13000 [1]. Though these effects are smaller or of the same size compared to the refrigerants being replaced, this is more and more seen as a problem. As a result this set of greenhouse gasses is included in the so-called baskets of the UN Kyoto-protocol; hence their emission is subject to control measures.

This situation has led globally already to regulatory initiatives to reduce the emissions of these substances by banning their use. Examples are that Denmark and Austria have restricted the use of HFCs in certain applications. On a European level, the so called F-gas regulation [3] with its link to MAC directives, bans the use of HFCs with a GWP above 150 in automotive air conditioning for new car types as of 1/1/2011, next to imposing measures on the containment and servicing of HFC containing appliances.

As the Kyoto-protocol deals in principle with emissions only, rather than prohibiting the use, it has been brought forward by various countries (among which the USA) to include HFCs, despite their zero ozone depletion potential, under the Montreal Protocol and to include a phase out scenario of these refrigerants. Though not active yet, this does clearly illustrate that the use of these refrigerants is under increasing pressure.

The lessons which can be learned by the earlier phase out of CFCs is that equipment operating with such refrigerants can in general still be used through its lifetime if no servicing of the refrigeration circuit itself is needed. Changes in legislation may however impact the serviceability of a product. As an example, using new HCFC-22 in existing installations, such as air conditioning systems, is forbidden since 1/1/2010 in Europe, while it well known that there is not enough recycled refrigerant available to service the sector. This forces system owners to costly early replacements or retrofitting their systems to new refrigerants (which are often HFCs at this moment in time).

RELEVANT HYDROCARBON REFRIGERANTS

As a response to the global warming contribution of HFC refrigerants, another class of refrigerants has come into the picture, the hydrocarbons (HCs), which only have a very low GWP. Though generally having quite good properties for refrigeration systems, their main draw back is their flammability. In the applications were only a limited amount is needed, this may be handled by adequate measures. Under the pressure of especially environmental organisations such as Greenpeace, the use of hydrocarbons became popular in domestic refrigeration and has now become state of the art. Other application areas have followed or are under development, where especially the commercial refrigeration sector is relevant.

Refrigerant	Refrigerant Number[2]	Boiling point [°C]	Auto-Ignition temperature [°C]	Maximum practical limit [g/m3]	Example of use
Ethane	HC-170	-88.6	515	8	
Propylene	HC-1270	-47.7	455	8	
Propane	HC-290	-42.1	470	8	> 100,000 units of ice cream freezers produced annually
Cyclopropane	HC-270	-32.8		8	
Dimethylether	HE E-170	-24.8	235	11	
Iso-butane	HC-600a	-11.7	460	8	> 50,000,000 units of domestic refrigerators produced annually
Butane	HC-600	-0.5	365	8	

For ultra-low temperature freezers down to -80°C, it is particularly relevant that ethane is available as a low boiling point HC. By mixing it with other HCs, properties can be obtained which allow replacing HFC based low temperature refrigerants. HCs were already known to be added to the HFC refrigerants to assist oil return. In general HC refrigerants can be used with mineral oils, which eases their use compared to HFC refrigerants that require other lubricants, such as polyolesters (POE), which are more difficult to handle in the field due to their hygroscopic nature. For low temperature freezers down to -40°C, it is possible to apply propane or, when the cooling capacity is not sufficient, propylene.

RELEVANT SAFETY STANDARDS AND APPLICATION

In several European electro-mechanical safety standards, already special considerations for products containing flammable refrigerants are included or are being discussed within the relevant standardisation bodies. Here an example is discussed which relates to the conversion of an existing laboratory freezer (DF8514GL, make Skadi Europe in The Netherlands, www.skadi-europe.com) to hydrocarbon refrigerants. The relevant European standard applied is EN 60335-2-24 [2].

According to clause 22.106 of this standard, the mass of flammable refrigerant shall not exceed 150 gram in each separate refrigeration circuit. For the appliance under evaluation containing two separate cascade refrigeration systems this limit of 150 gram was not a problem.

The standard makes a difference between so-called protected and unprotected cooling systems. For the specific freezer evaluated no parts of the cooling system were placed inside the storage compartment and therefore this freezer is considered to be a protected cooling system.

Figure 2. Possible ignition source locations which were updated in order to obtain a safe hydrocarbon refrigeration system.

For both protected as well as unprotected cooling systems, amongst others, it needs to be evaluated if a possible leakage of refrigerant could lead to explosions in areas outside the storage compartment were system components possibly producing arcs or sparks are mounted. Clause 22.109 of the standard explains exactly how these evaluations are to be performed. In short the test comprises that a certain gas flow (simulation of a leakage) at positions of pipe work joints of the cooling system is created. During this leakage simulation, the gas concentration near hazardous electrical components is to be measured. The measured concentration shall not exceed 75% of the lower flammability limit at all and shall not exceed 50% of the lower flammability limit for a period longer than 5 minutes.

Prescribed gas leakages were created on different positions (near pipe work joints) and the gas concentration has been measured at the hazardous electrical components indicated in *Figure 2*.

In the original configuration, too high gas concentrations were measured near several hazardous electrical components positioned at the bottom of the electrical component box and also near the thermostat. The electrical component box contained openings for cable transits and component fixtures. Through these holes the gas apparently enters the box. It was concluded that applying a sealed box with sealed cable transits would be the major part of the solution to convert this cabinet to a hydrocarbon refrigerant. Components that could not be placed inside this sealed box had to be replaced by electrical components complying with IEC 60079-15:2005, section 4. In the new updated Skadi Green line product, these modifications have been applied.

Next to the components producing arcs or sparks it also needs to be evaluated if the system contains any surfaces, which may be exposed to flammable refrigerants that become too hot. According to clause 22.110 temperatures should remain below the ignition temperature of the relevant refrigerant reduced with 100°C. Regarding this clause especially (but not only) heaters should be verified (e.g. evaporator defrost heaters and water condensation heaters).

Obviously these are only examples of the evaluations needed to be performed. For a conversion to flammable refrigerants of any appliance all relevant clauses of the EN 60335-2-24 should be carefully followed.

BENEFITS IN ENERGY USE AND CO_2 EMISSION

In many applications hydrocarbons outperform HFC refrigerants due to favourable thermodynamic properties. Though a full analysis may require a very detailed investigation, it is possible to calculate the efficiency of a theoretical refrigeration loop using different refrigerant. In praxis the efficiency will be influenced by matters as compressor optimisation towards each refrigerant, but it is a well know method to screen refrigerants on first principles. The results are shown over an evaporating temperature range in *Figure 3* for a typical single stage freezer. In praxis the evaporation and condensation temperature may change due to differences in heat transfer between refrigerants. This works out generally favourable for the hydrocarbons, so the efficiency difference as shown in the diagram is somewhat conservative.

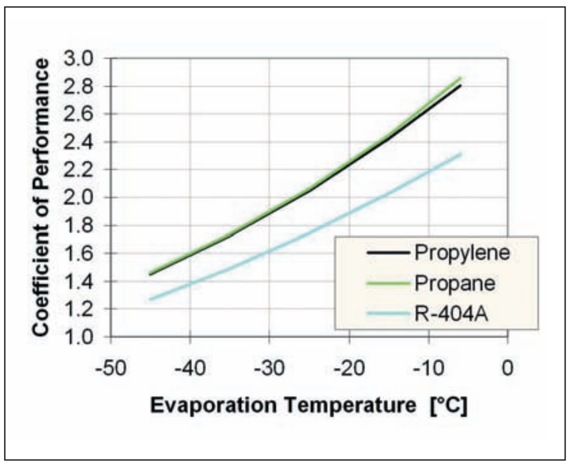

Figure 3. Efficiency for different refrigerants, the conditions applied are: condensation temperature 45°C, liquid subcooling 2 K, superheat in the evaporator 5 K, internal heat exchanger with an efficiency of 70%.

In principle the use of a laboratory freezer during its lifecycle has two effects on global warming: a direct effect due to the refrigerant emission at end of life (if not recovered) or during servicing and an indirect effect due to the CO_2 emission involved with the electricity generation to drive the freezer. These factors are taken together in the so-called TEWI factor. If an example case is taken for the same single stage low temperature freezer that is converted from R-404A to propane the following calculation can be made (a 15% energy consumption reduction is assumed as derived from *Figure 3*):

	Baseline	After conversion
Refrigerant	R-404A (300g)	Propane (HC-290) (150g)[6]
Energy Consumption [kWh/24h]	10.0	8.5
System leakage (% over life time)	2%	2%
Life time	10 years	10 years
Recovery at end of life	0%	0%
Refrigerant GWP [kg CO_2 eq.]	3900	20
Direct contribution [kg CO_2]	1193	3
Indirect contribution [kg CO_2][7]	22995	26674
TEWI (Total Equivalent Warming Impact) kg CO2 emission during life cycle	24188	19548 (-19%)

CONCLUSIONS

As current refrigerants employed in laboratory freezers or coolers do have a contribution to the greenhouse effect when emitted, their use is under continuous increasing pressure. It is possible that limitations for using these refrigerants in certain countries or regions will be put in place, which may also have a negative impact on future servicing. Hydrocarbons form an excellent solution for this application, provided these are applied with careful consideration to the safety of the products. Current electro-mechanical safety standards do already contain provisions for using such, flammable, refrigerants. The current paper has shown a few examples of safety testing and redesign needed to accommodate these refrigerants. As hydrocarbons do generally lead to energy savings compared to the current, HFC based, refrigerants for the laboratory freezers, these refrigerants must be seen as good alternatives to reduce the environmental impact of these products.

REFERENCES

1. *UNEP 2006 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, 2006 Assessment*

2. *EN60335-2-24 Household and similar electrical appliances – Safety – Part 2-24: Particular requirements for refrigerating appliances, ice-cream appliances and ice-makers.*

3. *Regulation (EC) No 842/2006 of the European Parliament and of the Council of 17 May 2006 on certain fluorinated greenhouse gases.*