ICE CREAM CABINETS USING A HYDROCARBON REFRIGERANT: FROM TECHNOLOGY CONCEPT TO GLOBAL ROLLOUT

RENÉ VAN GERWEN [1), ALAN GERRARD [2), FABIO ROBERTI [3)

[1) Global Lead Engineer Refrigeration & HVAC
Unilever Engineering Excellence Team EET
Olivier van Noortlaan 120, 3133 AT Vlaardingen, The Netherlands
rene-van.gerwen@unilever.com

[2) Senior Technologist
Centre of Excellence Ice Foods
Unilever Foods R&D
Colworth Science Park, Sharnbrook, Beds MK44 1LQ, UK
alan.gerrard@unilever.com

[3) Cabinets Test Unit Manager
Cabinet Test Unit
Via Paolo di Dono 3/a
00142 Rome, Italy
fabio.roberti@unilever.com

ABSTRACT

In 2000, the world largest ice cream producer Unilever made a commitment to implement by 2005 a non-HFC purchasing policy for ice cream freezer cabinets in all countries where commercially viable alternatives can be legally used. After thoroughly investigating all alternatives, R290 (Propane) has been chosen as the replacement for HFCs in this application. Between 2000 and 2003, small scale trials have been performed, and measurements in the field showed that there was no significant difference in reliability and performance between R290 and HFC cabinets. As a side-effect, the cabinets using R290 appeared to be more energy efficient. Supporting work has been undertaken to assess and quantify the risks of using R290. As a result of this work, some very minor changes to the design of these cabinets have been identified, in order to further minimise the risks. Recognising that servicing (maintenance and repair) activities on those cabinets represent the highest risk, a detailed training package for maintenance & repair technicians has been developed and made available to servicing companies. Since 2003, R290 cabinets are being rolled out globally, and by mid 2008 about 270,000 units operate in the field (of a total fleet of more than 2 million). Data from the field and from climate room tests reconfirm that there is no difference in safety, reliability and performance between cabinets with R290 or HFC refrigerants, and that the R290 cabinets are more energy efficient.

1. INTRODUCTION

In 2000, the world largest ice cream producer Unilever made a commitment to implement by 2005 a non-HFC purchasing policy for ice cream freezer cabinets in all countries where commercially viable alternatives can be legally used. As a consequence of this commitment, several focused activities have to take place in order to meet this challenging commitment within the available time frame.

A clear refrigerants strategy is required and a technology concept should be developed, including thorough assessment of the safety aspects and defining specifications. Field tests and climate room tests support this development. An economically sound business case should be created, and finally a rollout strategy has to be developed and implemented. The next sections describe these steps in more detail.

2. REFRIGERANTS STRATEGY FOR ICE CREAM FREEZER CABINETS

Several steps in the refrigerants strategy can be identified. In 1996, Unilever implemented a policy to stop buying new CFC containing equipment, including the refrigerant as well as blowing agent for insulation foam. A disposal policy for ice cream cabinets has been mandated by 2003.
A major step has been made in 2000, where Unilever committed to implement a non-HFC purchasing policy for ice cream freezer cabinets in all countries by 2005, where commercially viable alternatives can be legally used.
So since 2000, several focused activities started in order to meet this challenging commitment. First step was a detailed search for and assessment of alternative refrigeration solutions (Gerwen, 2001), resulting in a better understanding of the potentials, opportunities and challenges. Other initiatives included, amongst others, developing and testing the world's first prototype thermo-acoustic freezer which uses sound waves (Poese, 2004), investigating the use of energy-saving solar power in refrigeration, and investigating magneto-caloric refrigeration concepts.
It became clear that hydrocarbons (HCs) had were best suited to meet the HFC-free commitment within the available time frame, as this technology as such is proven to be reliable and efficient; equipment and components are commercially available and not intrinsically more expensive. HCs became Unilever's focus for implementing the HFC-free policy. Recognising that energy efficiency was an important consideration, any alternative technology should be at least as energy efficient as the equivalent HFC version.
In order to help equipment manufactures and suppliers in defining their strategy, several end-user companies of point-of-sales refrigerated equipment joint their forces in 2001, in an alliance called Refrigerants, Naturally, for sharing technical know-how, collaborating on initiatives and encouraging other companies to eliminate greenhouse gases from refrigeration equipment. Unilever, Coca-Cola and McDonald's were the initiators, joint by PepsiCo, IKEA and Carlsberg in 2007. The initiative is supported by Greenpeace and United Nations Environment Programme.

3. TECHNOLOGY CONCEPT FOR HYDROCARBON REFRIGERANTS

3.1. Risk Assessments

Hydrocarbon's flammability requires a full understanding of their safe use in ice cream cabinets. Qualitative risk assessments found in literature, including widely accepted international safety standards, showed a variety of contradictory information. The preferred way of assessing safety is by using quantitative methods. The quantitative risk assessment (QRA) technique is widely accepted in the petrochemical industries, but rarely used in refrigeration. Gerwen et al.(1994) already explained at the first IIR conference on natural refrigerants the value of this technique, and the results when applying QRA's to ammonia and hydrocarbons. A QRA basically identifies all major scenarios with an expected significant risk, and then calculates effects (consequences) and probabilities/frequencies for all these scenarios, where the risk is determined as the multiplication of effect and probability/frequency. Scenarios, effects and probabilities/frequencies are very specific for the kind of equipment and way of operation concerned. The total (cumulative) risk is the sum of all these risks for each scenario. Risks are defined as personal/individual (lethal) risk (risk for an individual in terms of frequency number per year) and as lethality risk, where the actual presence of persons at the location is taken into account. Sometimes also a group or societal risk is defined.
The QRA technique has been used for a standard Unilever ice cream cabinet (horizontal, sliding glass lids on top, 360 litres product storage volume, evaporator and skin condenser integrated in the cabinet walls, 90 gram of Propane in the refrigeration system). The QRA study from Elbers and Verwoerd (2005) confirms that the individual and lethality risks during normal operation of the cabinet are far below generally acceptable levels. There is no group or societal risk identified. The QRA recommends several minor changes in the design to further reduce the risk (see section 3.3). Similar QRA work done by Colbourne and Suen (2003, 2004) reconfirms that risks during normal operation are below generally acceptable levels. Indicative risk calculations showed higher values for service (maintenance and repair) activities. In order to minimise the risks during maintenance and repair, detailed training material has been developed for helping service technicians in understanding the specific issues related to hydrocarbon refrigerants. (Gerrard, 2005), including a competence test.

3.2. Regulations and Standards

In almost all countries in the world, national regulatory requirements allow the use of hydrocarbon refrigerants, where the refrigerant charge determines eventual additional safety precautions.

USA EPA Significant New Alternatives Policy (SNAP) Program consists of a specific approach to evaluate and regulate substitutes for the ozone-depleting chemicals, defining acceptable and unacceptable alternatives. Any interested party may petition EPA for consideration of an alternative, and request for a certain time period to test or collect supporting material. The American Underwriters Laboratories Standard UL 471 for Commercial Refrigerators and Freezers has recently been amended to take account of the use of flammable refrigerants in small commercial refrigeration equipment.

European standard EN 378 (2008) (Refrigerating systems, safety and environmental requirements allows factory sealed refrigerating systems with less than 0.15 kg of flammable refrigerant to be used in any application and location. For larger refrigerant charges, EN 378 contains an allowable charge calculation method, where the result depends on the practical limit (0,008 kg/m³ room volume for R290), occupancy category, system location and system design details.

Several other international standards (e.g. the ISO/EN/IEC 60335-2 series of standards on safety of household and similar electrical appliances) contain specific requirements for the use of flammable refrigerants which may be applicable to ice cream cabinets. Some of these requirements are contradictory, but all of them tend to accept flammable refrigerants up to 150 grams per refrigerant circuit. However, not any scientific foundation of this limit of 150 gram has been found.

In order to avoid any potential conflict with any international safety standard, the decision has been made to apply R290 in ice cream cabinets up to a limit of 150 gram of refrigerant per circuit.

3.3. Functional Specifications

In order to further minimise the risks associated to the use of hydrocarbon refrigerants, functional specifications have been developed. These specifications aim to support manufacturers in their design of ice cream cabinets. A functional specification clarifies that the cabinet manufacturer is still responsible for the cabinet design and its safety, and protects the purchaser against legal liability as ‘quasi-vendor’. The end user expects companies supplying them with cabinets to ensure that the design and manufacture of the cabinets minimise the risks. In particular the companies will be expected to ensure that:

a) Any potential ignition sources in the equipment have been identified and eliminated at the design stage

Any unsealed or non-solid state electrical component is a potential ignition source. In ice cream freezers, potentially sparking electrical components may include (without limitation):

- Loose electrical connections
- Unsealed compressor relay
- Unsealed compressor overload protector
- Connections to start and run capacitors
- Thermostat body
- On / off switches
- Case lighting
- Light switches

Unilever expects suppliers to have checked all components and to have a cabinet design that eliminates these potential problem areas. This could be achieved by:

- Replacing the electrical components with sealed or explosion proof types
- Replacing the electrical components with solid state types
- Putting the electrical components in a sealed enclosure

Loose connections also have a potential to spark, and wherever possible, connections should be made in a way that reduces this risk. It is obvious that local or international regulations should be followed if appropriate. The number of connections should be minimised.

b) The design and manufacture minimises the possibility of leaks occurring

It is recommended that:

- All joints should be brazed or welded – mechanical joints should not be used
- There should be as few joints as possible

Leakage of HC refrigerants into the ice cream cabinet represent a risk, as the HC can accumulate there, and it is difficult to disperse. Leakage can be minimised if the evaporator and the (skin) condenser are each made out of one length of copper tube.
Accumulation of HC refrigerant in the refrigeration (compressor) compartment must be minimised by the provision of sufficient ventilation.

c) The cabinets and refrigeration components are clearly labelled and documented
It is strongly recommended to follow appropriate ISO, IEC, CEN or CENELEC standards. As many of these standards are in a revision process, suppliers' documentation should explicitly refer to these specific standards and their date or version.
Sufficient labels must be provided on the cabinet to ensure that customers and service engineers are clear that the cabinet contains flammable gas and a warning that only qualified engineers should be working on the equipment. This should appear on the outside of the cabinet, on the compressor and the sealed box (if used). International or locally recognised symbols should be used.
Leaflets or similar documentation accompanying the cabinet should also contain similar statements.

An important functional specification is related to the choice of refrigerant. As a result from a literature search, Propane (R290) has been identified as the best suitable hydrocarbon refrigerant for ice cream freezer cabinets. This choice has been confirmed by Resch (2008).

3.3. Business case

Finally, the technology concept should be economically viable, particularly for a rollout in larger quantities. Many technically promising benign alternatives for HFC refrigeration suffer under poor economical feasibility, partly because of intrinsically more expensive technology (e.g. high pressures for CO_2), partly because of lower initial production volumes. In this respect, the purchase costs of the equipment are the dominant economical factor. In this phase, it is important to collaborate with major cabinet manufacturers/suppliers in order to optimise costs. In this respect it is very helpful to have a well controlled global buying structure in place where a limited number of global cabinet suppliers can meet customer needs..
Hydrocarbon technology showed to be largely cost neutral when compared with conventional HFC technology. Additional requirements on electrical safety and leak tightness do not result in significant cost increase, the refrigerant as such is cheaper than HFC, and all system components are almost the same as those for HFC technology.

4. FIELD TESTS

In order to gain experience with the technology, the process of risk assessments and definition of specifications, has been supported by small scale field tests. Objectives were to identify safety, reliability and energy consumption effects of using hydrocarbons in place of HFC. During the Olympic and Paralympic games in Sydney, in 2000, 25 standard freezers using HFC R404A as refrigerant, and 50 standard freezers using hydrocarbon propane R290 as refrigerant, have been used for ice cream sales, mainly on the street (Figure 1). The only difference between both types of cabinet is the refrigerant. The trial has been continued in a second phase in Sydney and Brisbane, where cabinets have been located in gas stations, shops and supermarkets. During the field tests, each cabinet was fitted with two temperature data loggers to record the temperature inside and outside the cabinet and a power meter to record the energy consumption. The whole field test has been carefully supervised by an external expert organisation, and reported by Elefsen et al. (2002). Based on the two field tests, it can be concluded that the new HC freezers operate with a similar reliability as the HFC freezers. No safety issues have been observed. Based on the measurements from the two field tests, it can furthermore be concluded that the new R290 freezers use approximately 9% less energy than the standard R404A freezers (Figure 2).

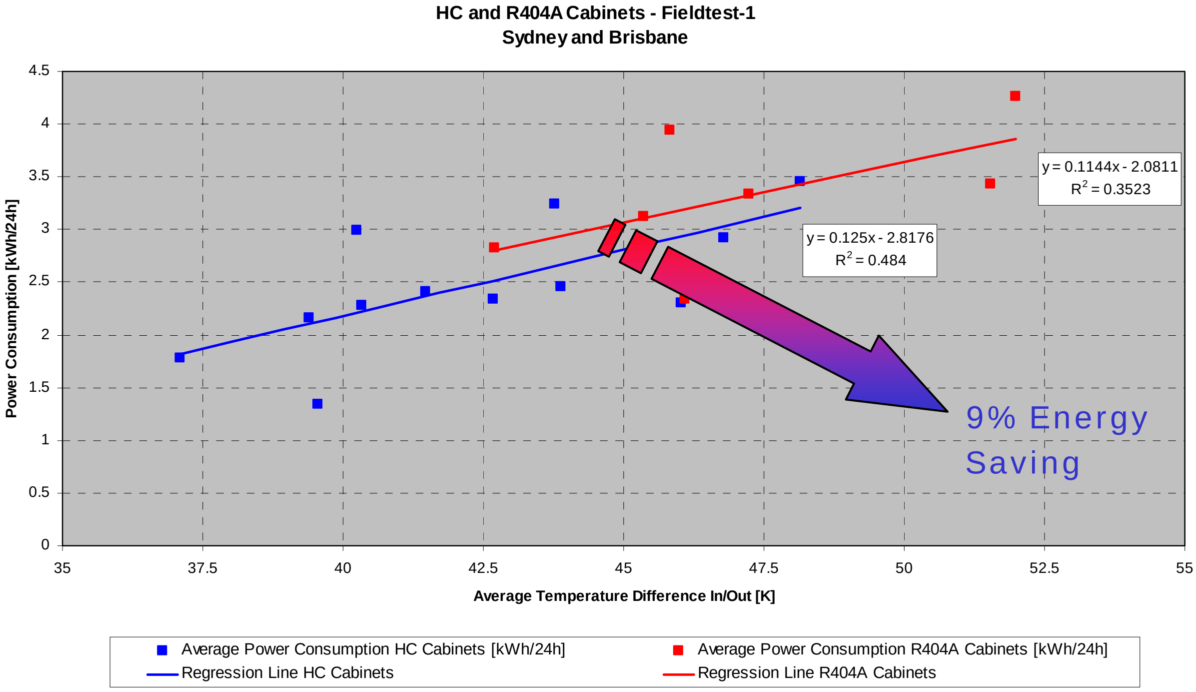

Figure 2: Field test results on power consumption versus average temperature difference inside and outside the cabinet, for both R290 and R404A

5. CLIMATE ROOM TESTS

The Unilever Cabinet Test Unit in Rome has two climate test rooms where different ambient conditions in terms of temperature and relative humidity can be reproduced. The test rooms and test procedures comply with EN 441 and subsequent ISO 23953 (2005). Cabinets are loaded with standard tylose packs, some of them provided with Pt 100 temperature sensors, connected to Yogogawa printing recorders. Data are collected and stored on a Personal Computer. Tests are carried out according to EN 441/ISO 23953 standards at different climate classes. Each room is provided with an automatic pneumatic system for carrying out lid opening tests, simulating selling periods as happening during normal operation. Since 2001, when the Test Unit was installed in Rome, around 250 cabinets have been tested.
Tests on hydrocarbon refrigerant cabinets started since 2002. Neither during laboratory tests nor from the field in different countries, did HC cabinets show any issue regarding their safe use, reliability or frequency of maintenance/repair.
An important element in the performance of hydrocarbon refrigerant cabinets is the energy consumption. In Table 1, a comparison between the results of energy consumption tests of several horizontal closed cabinets with glass lids is presented for both HFC and HC versions. Energy consumption tests are according to EN 441/ISO 23953-2, Climate Class 4 (+30°C / 55% R.H.), being representative for the average ambient climate for cabinets during normal heavy duty operation.

Table 1: Comparison of measured electricity consumption for HFC and HC cabinets, according to EN 441/ISO 23953-2, Climate Class 4 (+30°C / 55% R.H.).

	Electricity Consumption				
	HFC refrigerant R404A		**HC refrigerant R290**		**HC vs. HFC**
Cabinet type	***kWh/24h***	***Wh/24h per litre***	***kWh/24 h***	***Wh/24h per litre***	***%***
Horizontal Angle Top single glass lid Net volume 252 litres	4.4	17.5	3.8	15.1	-14
Horizontal Visi Top single glass lid Net volume 288 litres	3.6	12.5	3.2	11.1	-11
Horizontal Visi Top single glass lid Net volume 364 litres	4.6	12.6	4.2	11.5	-9
Horizontal Angle Top single glass lid Net volume 258 litres	4.4	17.1	4.0	15.5	-9
Horizontal Visi Top single glass lid Net volume 117 litres	2.9	24.8	2.7	23.1	-7
Average consumption per 24 h per litre		16.9		15.3	-10
Maximum		17.5		15.1	-14
Minimum		24.8		23.1	-7

	Electricity Consumption				
	HFC refrigerant R134a		**HC refrigerant R290**		**HC vs. HFC**
Cabinet type	***kWh/24h***	***Wh/24h per litre***	***kWh/24 h***	***Wh/24h per litre***	***%***
Horizontal Angle Top single glass lid Net volume 236 litres	4.9	20.8	3.3	14.0	-33
Horizontal Visi Top single glass lid Net volume 184 (R134a) - 203 (R290) litres	3.6	19.6	3.2	17.4 (15.8) [1)]	-11 (-19)[1)]
Average consumption per 24 h per litre		20.2		15.7 (14.9) [1)]	-22 (-26)
Maximum		20.8		14.0	-33
Minimum		19.6		17.4 (15.8) [1)]	-11 (-19) [1)]

1) Corrected for increased product volume (raising load line)

	Electricity Consumption				
	HFC refrigerant R507		HC refrigerant R290		HC vs. HFC
Cabinet type	***kWh/24h***	***Wh/24h per litre***	***kWh/24 h***	***Wh/24h per litre***	***%***
Horizontal Angle Top single glass lid Net volume 242 litres	6.7 (R507)	27.7	3.5 (R290)	14.5	-48
Horizontal Angle Top single glass lid Net volume 332 (R507) - 351 (R290) litres	6.5 (R507)	19.6	4.9 (R290)	14.8 (14.0) [1)]	-25 (-29) [1)]
Average consumption per 24 h per litre		23.6		14.6 (14.2) [1)]	-36 (-39) [1)]
Maximum		27.7		14.5	-48
Minimum		19.6		14.8 (14.0) [1)]	-25 (-29) [1)]

1) Corrected for increased product volume (raising load line)

The Table 1 shows that there is a large spread in daily electricity consumption per litre of storage volume for different models, for both HFC and HC refrigerant. This large spread is expected to be caused by the relatively large size steps (swept volume) for commercially available compressors, suitable for the dimensions of the cabinet. In some cases, the additional refrigerating capacity allowed to increase the net volume by raising the load line level.
From this table it can be concluded that the hydrocarbon refrigerant cabinets use significantly less electricity than the equivalent HFC types, with a weighted average of 18.4 %, tested in a climate room under test conditions according to Climate Class 4. Compared with the HFC R404A reference only, the average is 10 % saving, being in line with the measured saving of 9 % during the field tests (see section 4). The savings compared with the HFCs R134a and R507 references are much larger, partly because of the properties of those HFC refrigerants, partly because of non-optimised compressor sizing or system design.

6. GLOBAL ROLLOUT

For any new technology concept to be placed on the market, a well-based rollout plan is required in order to ensure smooth and safe processes for purchasing/selling, operation and maintenance/repair.
For this, a Hydrocarbon Refrigerants in Ice Cream Rollout Summary Document has been developed (Gerrard and Van Gerwen, 2004), to be used as guidance for a country-specific introduction of this technology. This document covers:

- Background, refrigerants phase-out policy, why the choice for hydrocarbons has been made
- Country-specific Introduction Programme (including required information, suppliers contact, service organisation contact, sales force contact, PR launch plan, logistics)
- HC properties, introduction to flammability, general safety issues
- Functional specifications
- FAQ&A sheet
- Servicing details & training material
- MSDS for R290
- Customer fact sheet

In several countries, the introduction has been supported by a media event, helping in creating the awareness of a broader audience, and further improving local market acceptability of this new technology.

Introduction started in 2004 in Denmark (700 R290 cabinets). By mid 2008, around 270,000 R290 cabinets are in operation in most European countries and in several countries in Asia and Latin America.
In North America, a formal EPA-SNAP approval process for R290 is initiated by mid 2008.

7. CONCLUSIONS

Developing and rolling out new refrigeration technologies for certain applications is challenging and needs careful preparation and management. The choice for R290 as alternative refrigerant for ice cream cabinets made it possible to meet company commitments on HFC replacement. Thorough scientifically based assessments of the risks, practical field and climate room tests, and a structured rollout plan contributed to the success of this technology, where by mid 2008, 270,000 R290 ice cream cabinets operate in the field.
In field and climate room tests, R290 cabinets were shown to be significantly more energy efficient than the equivalent HFC cabinets.

REFERENCES

Gerwen, R. van et al, 2002, Perspective of novel refrigeration technologies SENTER/NOVEM contract 375007/0060, Final Report

Poese, M.E., Smith, R.W.M., Garrett, S.L., Gerwen, R. van, and Gosselin, P, 2004, Thermoacoustic refrigeration for ice cream sales, International Institute of Refrigeration 6th Gustav Lorentzen Conference - Natural Working Fluids, Glasgow UK

Gerwen, R. van et al: , 1994, Risk Assessment of Flammable Refrigerants, International Institute of Refrigeration Conference: New Applications of Natural Working Fluids in Refrigeration and Air Conditioning, Hannover, Germany

Elbers, S. and Verwoerd, M., 2005, Quantitative Risk Assessment of an ice cream cabinet using hydrocarbon refrigerant, TNO-MEP Report R 2005/261, update of R2001/476, January 2002

Colbourne, D. and Suen, K.O.,2003, Equipment Design and Installation Features to Disperse Refrigerant Releases in Rooms, Part I: Experiments and Analysis, International Journal of Refrigeration, vol. 26, 6, 667-673.

Colbourne, D. and Suen, K.O., 2003, Equipment Design and Installation Features to Disperse Refrigerant Releases in Rooms, Part II: Determination of Procedures, International Journal of Refrigeration, vol. 26, 6, 674-680.

Colbourne, D. and Suen, K.O., 2004, Appraising the flammability hazards of hydrocarbon refrigerants using quantitative risk assessment model Part I: modelling approach, International Journal of Refrigeration, vol. 27, 7, 774-783.

Colbourne, D. and Suen, K.O., 2004, Appraising the flammability hazards of hydrocarbon refrigerants using quantitative risk assessment model. Part II. Model evaluation and analysis, International Journal of Refrigeration, vol. 27, 7, 784-793.

Gerrard, A, 2005, Safe Servicing Training Package for Hydrocarbon Ice Cream Cabinets, Unilever Ice Cream (available upon request)

Resch, R., 2008, Hydrocarbons: should you make the switch? RAC Conference Future Proof Cooling, London, UK

Elefsen, F., Nyvad, J., Gerrard, A. and Gerwen, R. van, 2002, Field test of 75 R404A and R290 ice cream freezers in Australia, International Institute of Refrigeration 5lh Gustav Lorentzen Conference - Natural Working Fluids, Guangzhou, China.

Gerrard, A, Gerwen, R. van, 2004, Hydrocarbon Refrigerants in Ice Cream Rollout Summary Document, Unilever Ice Cream, (parts available upon request)