OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

FAIR USE POLICY

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

22818

UNIDO PROJECT No MP/CPR/00/157

Contract No: 01/036

FINAL REPORT

THE CONVERSION OF DOMESTIC REFRIGERATORS AND FREEZERS AND THEIR MANUFACTURING TECHNOLOGY AT LITTLE SWAN ELECTRICAL Co Ltd, CHINA

ANDREW GIGIEL

16 September 2002

Food Refrigeration and Process Engineering Research Centre (FRPERC)

Churchill Building

Langford

Bristol

BS40 5DU UK

Tel +44 (0)117 928 9239

Fax +44 (0)117 928 9314

e-mail frperc-bristol@bristol.ac.uk

FOOD REFRIGERATION AND PROCESS ENGINEERING RESEARCH CENTRE

INTRODUCTION

The use of R12 as a refrigerant in refrigerators and freezers manufactured by Little Swan is being phased out and will be replaced by R600a. This contract with UNIDO was to provide assistance to Little Swan on the redesign and conversion of the cooling circuits of their domestic refrigerators.

This document reports on the progress of the whole contract and covers the training of local staff in redesign of circuits, transfer of information on product safety, transfer of technical, technological and safety information on R600a, the identification of components to be modified or replaced, the conversion and testing of 5 of Little Swan's refrigerators and on the training in safety testing of the refrigerators.

A first visit for 2 weeks was made to little Swan in August 2002, 5 Little Swan engineers attended a 2-week training course at Bristol in November 2001 (separate contract), 5 Little Swan refrigerators were converted at Bristol in 2002 and a second visit was made to Little Swan in September 2002.

TRANSFER OF TECHNICAL, TECHNOLOGICAL AND SAFETY INFORMATION ON R600A

A manual on "The Conversion And Redesign Of Cooling Circuits In Domestic Refrigerators From R12 To R600a" giving all necessary technical, technological and safety information on R600a and the differences between R12 and R600a has been prepared and sent in advance of the first visit to Little Swan. A copy of this manual has been emailed to UNIDO and is also attached to this report. Little Swan has translated this manual into Chinese in advance of the visit and distributed a copy to each of the five engineers in the project team, lead by Mr Cai Wen Bo.

During the 1st visit an ongoing workshop on this subject was given, covering 10 days, by lectures, teaching sessions in which the Little Swan engineers played an active part and in practical workshops. The practical workshops consisted of fully instrumenting 5 refrigerators (on the production line), testing them with R12 as the refrigerant, interpreting the results, converted them to R600a, retesting them, and modifying them from the original conversion in order to bring the performance into line with that of the R12 versions.

TRANSFER OF INFORMATION ON PRODUCT SAFETY

A manual on "The safety of domestic refrigerators and freezers with flammable refrigerants", giving all product safety information relating to flammable refrigerants, **EN 60335-2-24:1994** and Amendments A51 1995, A52 1997, and A53 1997, was given to Little Swan during the first visit. This was updated on the issuing of **EN 60335-2-24:2001** and the updated version given to Little Swan during the second visit. This standard is the relevant standard regarding the safety of domestic refrigerators and freezers with flammable refrigerants and is based on **IEC 60335-2-24:2000**. A copy of the updated manual is attached to this report.

A lecture on product safety, as defined by this standard, was given during the first visit. A workshop on safety testing under this standard was given during the second visit. This consisted of lectures and discussions on the requirements and purposes of the standard, how to carry out the tests and practical workshops on the preparation and testing of Little Swan's BCD208 fridge-freezer the whole taking 5 days.

TRAINING OF LOCAL STAFF IN REDESIGN OF REFRIGERATOR CIRCUITS

See transfer of technical, technological and safety information on R600a above.

IDENTIFICATION OF COMPONENTS TO BE MODIFIED OR REPLACED

Information was collected on locally available compressors, filter dryers and capillary tubes during the first visit. Five refrigerators (BC47, BCD208, BD170, SCD173 and the BD530) have been converted at Bristol and tested. Separate reports on the conversions and tests were prepared on each refrigerator and are listed in the Appendix of this report. Each of the refrigerators have been tested and show a equal or better performance to the original R12 model with the exception of the SCD173. In this model the energy consumption is 10% greater then for the R12 model. The reason for this was the unavailability of a suitable compressor in Bristol that would also be available in China. The compressor used for the conversion has a very low efficiency. A suitable compressor, manufactured in China, has been identified that will reduce the energy consumption by approximately 20%.

The conversions were discussed with the engineers at Little Swan. Little Swan was concerned with the need for long capillary tubes on several of the converted models. The reason was explained by the need to install additional capacity into the suction liquid heat exchanger without major disruption to the pre-foamed insulation. Methods of achieving the same performance in production models were discussed.

PROGRESS

The contract started on the 1 June 2001. All tasks that had been planned to be finished by the end of the 1st visit were completed by the end of August 2001. At this point the project was 2 months behind schedule. The reason for the delay was the length of time needed to organise the first visit and obtain Visas and plane tickets for China.

The training of the Little Swan engineers under a supplementary contract at FRPERC University of Bristol took place from 12 to 23 November 2001.

The conversion of the 5 refrigerators specified in the contract finished in July 2002. It had been planned that this work would finish in February 2002. The reason for the delay was that FRPERC had trouble arranging for enough test rooms for 10 refrigerators (5 for R12 and 5 for R600a) at 32 and 38C.

The progress made by the Engineers at Little Swan has been exceptional. This has been due to the dedication of the Company and the Staff (not just the Project Engineers), who have made every facility available and worked long hours to prepare refrigerators for practical workshops and by the very high standard of the translator they employed during the first visit and for the training in Bristol, Ms Lui Zhi.

APPENDIX

Deliverables

The conversion and redesign of cooling circuits in domestic refrigerators from R12 to R600a.

The safety of domestic refrigerators and freezers with flammable refrigerants.

Refrigerator Design and Energy Optimisation.

Conversion of a Little Swan BC47 refrigerator from R12 to R600a, Pull-down and continuous running tests.

Conversion of a Little Swan BC47 refrigerator from R12 to R600a, Storage tests at 16 and 32C.

Conversion of a Little Swan BC47 refrigerator from R12 to R600a, Energy consumption test.

Conversion of a Little Swan BC47 refrigerator from R12 to R600a, Specification of converted refrigerator.

Conversion of a Little Swan BD170 refrigerator from R12 to R600a, Pull-down and continuous running tests.

Conversion of a Little Swan BD170 refrigerator from R12 to R600a, Storage tests at 16 and 32C.

Conversion of a Little Swan BD170 refrigerator from R12 to R600a, Energy consumption test.

Conversion of a Little Swan BD170 refrigerator from R12 to R600a, Specification of converted refrigerator.

Conversion of a Little Swan BD530 refrigerator from R12 to R600a, Pull-down and continuous running tests.

Conversion of a Little Swan BD530 refrigerator from R12 to R600a, Storage tests at 16 and 32C.

Conversion of a Little Swan BD530 refrigerator from R12 to R600a, Energy consumption test.

Conversion of a Little Swan BD530 refrigerator from R12 to R600a, Specification of converted refrigerator.

Conversion of a Little Swan BCD218 refrigerator from R12 to R600a, Pull-down and continuous running tests.

Conversion of a Little Swan BCD218 refrigerator from R12 to R600a, Storage tests at 16 and 32C.

Conversion of a Little Swan BCD218 refrigerator from R12 to R600a, Energy consumption test.

Conversion of a Little Swan BCD218 refrigerator from R12 to R600a, Specification of converted refrigerator.

Conversion of a Little Swan SCD173 refrigerator from R12 to R600a, Pull-down and continuous running tests.

Conversion of a Little Swan SCD173 refrigerator from R12 to R600a, Storage tests at 16 and 32C.

Conversion of a Little Swan SCD173 refrigerator from R12 to R600a, Energy consumption test.

Conversion of a Little Swan SCD173 refrigerator from R12 to R600a, Specification of converted refrigerator.

UNIDO PROJECT No MP/CPR/00/157

Contract No: 01/036

WORKSHOP NOTES

THE CONVERSION AND REDESIGN OF COOLING CIRCUITS IN DOMESTIC REFRIGERATORS FROM R12 TO R600A.

ANDREW GIGIEL

15 July 2001

FOOD REFRIGERATION AND PROCESS ENGINEERING RESEARCH CENTRE

Food Refrigeration and Process Engineering Research Centre (FRPERC)

Churchill Building
Langford
Bristol
BS40 5DU UK
Tel +44 (0)117 928 9239
Fax +44 (0)117 928 9314
e-mail frperc-bris@bristol.ac.uk

The properties of R12 and R600a compared

Physical Properties

The most important physical properties of R12 and R600a for refrigeration use are shown in Table 1.

The structure of R12 is based on a single carbon atom, methane, with 3 chlorine atoms, whereas R600a is based on 4 carbon atoms. It differs from the straight chain n-butane in that one carbon atom is surrounded by the other 3 carbon atoms. The remaining bonds being with the hydrogen atoms. The chemical reactions reflect the differences. It is the lack of chlorine atoms that leads to the use of R600a to replace R12 as a refrigerant because it does not contribute any chlorine (or bromine) to the complex reactions that occur in the ozone layer.

The molecular mass of R600a is half that of R12 and the density of the liquid and vapour is in each case less than half that of R12.

R600a has a warmer boiling point at atmospheric pressure and operates at lower pressures than R12. However, the freezing point of the material, -160°C, is almost the same as R12, but as they are not used at very cold temperatures it need not concern us. The critical temperatures are more similar which does have a bearing on the choice of R600a as a replacement for R12.

There is a major difference in the specific heats of both the liquid and the vapour. This has an effect on the heat transfer properties of R600a and on liquid-vapour subcooling in a capillary line in refrigerator design. For a similar amount of heat transfer between the liquid and the vapour we can expect a smaller temperature change with R600a than we could with R12.

The density of the saturated vapour has an important bearing on refrigeration performance since systems normally have compressors with a constant volumetric displacement. They pump a fixed volume of refrigerant rather than a fixed mass. The lower density of the saturated vapour of R600a means that a smaller mass of refrigerant is pumped in unit time than R12, with the same compressor. However this is partially compensated for by an increase in the latent heat of vaporisation at a given pressure ratio. This is shown by the latent heat of vaporisation at atmospheric pressure for R600a being more than twice that for R12.

Thermal conductivity, viscosity and surface tension of the liquid and vapour are all important parameters governing the heat transfer during boiling and condensation of the refrigerant and are therefore included in this Table.

The vapour pressure at 25°C gives an indication of the normal working pressures that would be involved in handling the refrigerant, storage, and manufacture. The pressures are much lower for R600a than for R12.

Safety

Potential Hazards

The potential hazards are flammability, asphyxiation, burns, explosion and a narcotic sensation. These are taking one at a time.

Flammability

R600a is flammable in the following concentrations in air:

Lower (LEL) vol % 1.85

Upper (UEL) vol % 8.5

*LEL = lower explosive limit. *UEL = upper explosive limit.

An ignition source at a temperature greater than 460^0C is also needed for combustion to occur.

The use of flammable refrigerants is covered in British Standard 4434:1995 (Safety aspects in the design, construction and installation of refrigerating appliances and systems). It permits the use of hydrocarbons in many domestic, commercial and industrial applications. The British Standard has been revised in line with the draft European Standard (EN1012), which will eventually supersede it. An international standard is currently under discussion to bring the United States, Europe and Japan into complete agreement. The following table details the maximum allowable refrigerant charge weights corresponding to the occupancy category.

A	Not exceeding 1.5 kg in sealed systems. Not exceeding 5 kg in special machinery room for indirect systems.
B	Not exceeding 2.5 kg in sealed systems. Not exceeding 10 kg in special machinery room for indirect systems.
C	Not exceeding 10 kg in humanly occupied space. Not exceeding 25 kg in special machine. No restriction of charge if all refrigerant containing parts in special machinery room or in the open air.

Very small sealed systems with a refrigerant charge of 0.25kg or less may be sited in any location or category of occupation provided there are no sources of ignition, e.g. unsealed electrical contacts associated with the refrigerating system or located in an area where refrigerant could gather in the event of a leak.

For systems with a refrigerant charge greater than 0.25kg, the location is dependant on adequate room size or ventilation requirements in addition to there being no source of ignition associated with the system or in an area where the refrigerant could gather in the event of a leak.

The Standard specifies that the charge level in any system is related to the volume of the space into which the refrigerant could leak. The recommended maximum charges in the following table have been calculated from the lower explosive limit of the refrigerant (approximately 2% in air by volume). If the refrigerant is evenly dispersed in the room then the amount of refrigerant must be below the figure in the third column to prevent potential combustion. The maximum charge in the fourth column is between one fifth and one sixth of this to provide a high safety margin. The data in the table below illustrates some examples but values can be extrapolated for smaller or larger charges.

Room dimensions m	Room Volume m3	Max R600a in room uniformly dispersed	Max R600a in room with safety factor
2m x 2m x 2m	8	340 grams	70 grams
3mx3mx3m	27	1.1kg	200 grams
4m x 4m x 4m	64	2.7kg	500 grams
5mx5mx5m	125	5.2kg	1kg

The information in the above table relates to indoor systems. The Standard also covers the use of larger charges. In such applications, additional safety measures such as positive airflow, mechanical ventilation, leak detectors or gas sensors, together with the use of sealed or non-sparking electrical components must be considered.

The control measures needed when using a flammable refrigerant are well understood in industrial systems because of the widespread use of ammonia in these systems.

In general, the following guidelines should be followed:

- limit the charge quantity to the suggested maximum charge and follow the recommendations regarding electrical components if the system is indoors with no additional safety measures;
- If the charge is above the recommended maximum, in addition to the above either,
- eliminate ignition sources within the enclosed space by using only sealed or non-sparking electrical components and eliminate naked flames within the enclosed space

or

- using permanent atmosphere monitoring designed to give an alarm if the refrigerant concentration in the air approaches the lower explosive limit.

EN 60335-2-24:1994 with Amendments A51 1995, A52 1997, and A53 1997 is the relevant standard regarding the safety of domestic refrigerators and freezers. This details specific requirements for domestic refrigerators and freezers and is covered in a separate document.

Asphyxiation

Because R600a and R12 are heavier than air they sink to the floor and the concentration can build up in confined, unventilated places. This is particularly true if the refrigeration plant is situated in basements below the ground. As a result, the breathable air is excluded from these areas. If a person breaths this atmosphere they are at first unaware of the danger, since both refrigerants are odourless. The first sensation might be a light-headed feeling, dizziness, nausea or possible fainting. If the person loses consciousness in this atmosphere, death follows shortly afterwards due to asphyxiation.

It is thus very important to ventilate the area, especially so if there is a danger of building up a concentration of the gas at floor level. It must also be remembered by service personnel, working on chest freezers for example, when they are bending down inside the machine that the concentration of refrigerant can build up inside the chest and at least one service engineer in the United Kingdom has died, found with his head buried inside the chest of a frozen retail display case.

Burns

When the liquid refrigerant is released, it can come into contact with the eyes and skin. It boils at -12°C. This leads to severe burns where it is in contact, and if in the eyes, it can possibly lead to blindness. Every care must therefore be taken not to come into contact with the liquid refrigerant.

Decomposition in naked flames

Unlike CFCs and HCFCs, when R600a is burned in a naked flame no toxic decomposition products are given off. However, because of the risk of explosion, no sources of ignition should be present in an area where R600a can leak.

Cardiac sensation

At concentrations of more than 15% by volume in air, exposure to the vapour of R12 can lead to irregularities in the heart beat which, in severe cases, can induce a heart attack which in turn could lead to death.

Safety Precautions

Personnel working with the refrigerants should wear protective gloves, clothing and goggles, which will reduce the hazards due to coming into contact with the liquid.

It is important to ensure that the workplace or any area where people can go, and in which refrigerant can build up, is adequately ventilated at low level and that this ventilation cannot be restricted, for instance to reduce cold uncomfortable draughts.

There is no occupational exposure limit (OEL) for isobutane. As a guide the OEL for liquefied petroleum gas is 1000 ppm. This is the long-term exposure limit for an eight-hour working day, and is the same for R12 and other CFCs.

Cylinders of the gas should always be stored in well-ventilated areas, out of sunlight or other direct heat sources. The cylinders should be restrained and not standing in water. Adequate warnings should be displayed to alert people of their presence.

- small fires should be tackled with dry powder extinguishers, otherwise vacate the area and call the fire brigade;
- accidental releases of large quantities of hydrocarbon can be dispersed with a water spray. The area should be evacuated (except for personnel dealing with the emergency). Sources of ignition should be isolated or extinguished. If possible, the refrigeration system should be isolated at the point of leak.

Refrigerants should never be deliberately released into the atmosphere at any time. During service work, it is necessary to use a recovery machine to withdraw the refrigerant from the system into a safe cylinder so that it can be reused or disposed of safely.

When handling refrigerants from systems that have suffered an electrical burn-out, be aware that the refrigerant and the oil may be acidic, as a result of the high temperatures, and thus expose personnel to the additional risk of acid burns.

Handling of cylinders

Hydrocarbons are available in 300g, 3.5, 12 and 46 kg cylinders in the UK. There is a pressure relief valve to prevent the cylinder pressure becoming excessively high and a non-return valve. The cylinders have liquid off-take valves. The valves on the 3.5,12 and 46 kg cylinders have an 1 1/4in ACME connection. A fitting is available (Calor Gas Refrigeration part number 250486) to convert this to an industry standard thread suitable for most charging hoses. It should be removed when the cylinder is not in use or transported. The valve on the 300g cylinder has a 1/4in connection suitable for most charging hoses.

There is also a safety device known as an automatic excess flow valve within the liquid valve. It will operate and close the valve it the refrigerant flows out of the cylinder too fast (for example if a hose is not connected and the valve is accidentally opened). The valve is reset by closing it and opening again very slowly.

None of these cylinders is disposable.

Guidelines for safe cylinder handling differ very little from other refrigerant cylinders and are as follows:

- do not remove or obscure official labelling on a cylinder;
- store and use cylinders in dry, well ventilated areas remote from fire risk;
- do not expose cylinders to direct sources of heat such as steam or electric radiators;
- do not repair or modify cylinders or cylinder valves;
- always use a proper trolley for moving larger cylinders, even for a short distance - never roll cylinders along the ground;
- only use approved cylinder accessories;
- take precautions to avoid oil, water or foreign matter entering the cylinder;
- if it is necessary to warm the cylinder, use only water or air, not naked flames or radiant heaters. The temperature of the water or air must not exceed 40°C;
- always weigh the cylinder to check if it is empty - its pressure is not an accurate indication of the amount of refrigerant remaining in the cylinder;

Transport of Hydrocarbon cylinders

The Road Traffic (Carriage of Dangerous Substances in Packages) Regulations in the UK, commonly known as the Packaged Goods Regulations (PGR) apply to the transportation of hydrocarbon cylinders. These regulations apply if 2.5 kg or more is transported by road for business purposes. They also apply to other compressed gases such as oxy-acetylene. Failure to comply with the regulations will result in prosecution. In most cases, a refrigeration engineer will be carrying refrigerant in a closed van, less than 3.5 tonnes maximum permitted weight. To comply with the Regulations you must

- carry written information giving details of the hydrocarbon refrigerant(s). This can be the chemical safety data sheet (the COSHH sheet) or the Transport Emergency Card (the Tremcard). This must be readily available in an emergency, so it is recommended that it is kept on a clip board by the driver;
- know and understand the hazards of the hydrocarbon refrigerant and emergency procedures;
- carry two dry powder fire extinguishers of at least 1 kg capacity each. They must at least comply with British Standard rating 21 B. One must be located in the cab, the other in the load compartment and be accessible from the access doors (usually the rear doors). The driver must be trained in the practical use of the fire extinguisher;
- store cylinders upright and in a single layer. The cylinders must be secured;
- carry no more than 4 x 46 kg cylinders or 12 x 6 or 12 kg cylinders or 25 x 300g cylinders. If you have one 46 kg and either 6 kg or 12 kg cylinders you cannot carry more than 4 cylinders. Other flammable gases (eg for brazing) are also included in this allowance;
- have adequate ventilation in the vehicle (this may require modifications to a closed van although usually the leakage through doors and windows is likely to be sufficient);
- display flammable gas hazard warning diamonds on both sides and rear of van;
- remove the conversion fitting and cap all valves;
- never allow smoking or other naked flames;
- never leave cylinders in a closed van unsupervised or for longer than necessary.

The points listed above apply to closed vans and estate cars.

Storage of hydrocarbon cylinders

Wherever possible cylinders should be stored outside, except when they are being used.

This is not always possible for a refrigeration contractor. If the premises are residential then hydrocarbon cylinders must not be stored inside. The following points are guidelines for safe storage, assuming the cylinders are being stored inside and that the premises are not residential:

- where it is not practical to store cylinders in the open air the quantities stored should be restricted. For most refrigeration workshops no more than 5 cylinders or 70 kg of hydrocarbon can be stored inside;
- hydrocarbons should be stored at ground level and not below ground in cellars or basements. The cylinders should be readily accessible:

- hydrocarbons are odourless, so sensors should be used to detect low level leakage from cylinders:
- static electricity build up should be avoided.
- all cylinders to be stored in stillages or dedicated areas within the building and sited at least 1.5m from any possible source of ignition e.g. electrical switchgear or gas boilers.

Charging hydrocarbon refrigerants.

This section outlines correct charging procedure for hydrocarbon refrigerants.

In common with all refrigerant blends, blended hydrocarbons should be charged in the liquid phase to maintain the correct composition of the blend. It is important when charging a liquid into the system to take great care to ensure liquid refrigerant does not return to the compressor. This will damage the compressor and may result in complete failure.

Pure hydrocarbons such as R600a are single substances and can be charged as liquid or gas.

Pre-charging system processing

Before a system is ready to be charged with any refrigerant it should be tested for safety and leak tightness, and then evacuated to remove all gases and moisture. The pressures for the safety and leak testing are specified in BS 4434:1995. The pre-charging processing should be as follows:

1. Pressure test the system to 1.3 times the maximum working pressure (MWP). This should be done by increasing the system pressure slowly with dry nitrogen or helium to the required pressure, and then watching the pressure gauge for a short time to check that the pressure is not falling. This test is to check the mechanical safety of the system.
2. Leak test the system to 1.1 times the MWP. This can be done with the inert gas (dry nitrogen or helium) at the correct pressure and then each joint checked with a leak detection fluid (e.g. soapy water). Or the system can be charged to a pressure of up to 1 bar with refrigerant, and the pressure boosted with dry nitrogen or helium (never air) to the leak test pressure and each joint checked with a suitable electronic leak detector.
3. Evacuate the system to 200 microns (0.26mbar, 26Pa) to remove gases and moisture using a single evacuation process. It is especially important in a system to be charged with hydrocarbons that no air remains in the system. The evacuation should be carried out with a proper vacuum pump and the pressure measured with a vacuum gauge. Make sure that no parts of the system are isolated by closed valves. When the required vacuum is reached, the pump should be switched off and the gauge watched. If the pressure rises quickly, there is still a leak in the system. If the pressure rises slowly, moisture is present and is slowly evaporating, increasing the pressure. The length of time needed to evacuate a system depends on the capability of the pump and the size of the system.

An existing system to be converted should already have been pressure tested and leak tested. However, any joints made during the conversion procedure should be pressure and leak tested. The system must be evacuated in line with 3, above, before charging with the new refrigerant. More details are given in the drop-in procedure outlined later in this section.

General charging guidelines

These points are general guidelines to follow when charging hydrocarbon refrigerants:

- always charge blended hydrocarbons in the liquid phase to retain the blend composition in both the system and the cylinder;
- always use the cylinder in the upright position;
- use hoses which are as short as possible to minimise the amount of refrigerant contained in them;

If a large system is to be charged the charging equipment, hoses and system must be earthed to prevent a build up of static electricity. In smaller systems (i.e. domestic appliances, small commercial systems, transport refrigeration and air conditioning applications), the flow of refrigerant will be insufficient to generate static;

- always remove air from lines, preferably by evacuating the lines with a vacuum pump. If this is not possible the lines can be purged, with low pressure gas if possible, or very carefully with liquid, allowing as little refrigerant as possible to escape;
- avoid naked flames when charging. For example, there should be no smoking. Display "No Smoking" signs;
- have a dry powder fire extinguisher adjacent to the charging area;
- label the system when charging is complete. The label should be prominently positioned and should state that hydrocarbon, R600a, has been charged into the system and that it is flammable. Such labels are usually supplied with the refrigerant.

Charging using a charging still

When a charging still is used for blended hydrocarbons liquid refrigerant should be charged into the still, and liquid taken out. Great care should be taken if the only charging connection is into the suction line of the refrigeration system. It is possible to fit an expansion device into the line between the charging still and the suction line. This could be a simple capillary tube, which will evaporate the liquid before it enters the system.

If a pure hydrocarbon (such as R600a) is being used, gas can be taken out of the still.

Most charging stills measure the refrigerant by volume. The volume of hydrocarbon required will generally be the same as that of the CFC / HCFC refrigerant, corrected for volume. For example, when charging R600a into an R12 system, fill the charging still to the same level on the scale specified for existing charge of R12 and use this amount in the system. Although the still is calibrated in weight, it is actually measuring a volume.

Charging without a charging still

When a charging still is not used, liquid can be charged into the liquid line in the normal way. If it is required to charge a blended hydrocarbon into the suction line, (for example to top up a system or to complete the initial charging of a system) then an expansion device (for example a capillary tube) can be used to evaporate the refrigerant before it enters the system. Alternatively, the liquid can be throttled through a manifold set.

If refrigerant is weighed into the system, the charge of hydrocarbon will be approximately 40% that of the refrigerant it replaces, by weight.

The system can be charged until the liquid line sight glass clears. However, it should be remembered that bubbles in the sight glass do not always mean the system is undercharged. They can also indicate a blockage in the liquid line filter drier or that the condenser is seriously undersized.

If the weight of refrigerant is known, the correct charge of hydrocarbon could be decanted into a dual-port cylinder and then charged as liquid and gas into the system. This procedure is only worthwhile on systems with an accurately measurable charge weight.

Beware of overcharging

Because of the smaller weights likely to be involved with hydrocarbon charges, it is more likely that systems are overcharged because there is less margin for error. Great care should therefore be taken to accurately charge a small system. For example, there may be more refrigerant in the charging hose than is needed in a domestic appliance.

If a system is overcharged the excess should be recovered into a dedicated hydrocarbon recovery cylinder - it should not be vented to atmosphere as, if contaminated, it could be an offence under the Environmental Protection Act in the UK.

Leak Testing

The reason for leak testing

The purpose of leak testing is to ensure that the refrigerant remains in the system. If the refrigerant leaks out it will contaminate the atmosphere, cause a potential hazard if the concentration is large enough and lead to a deterioration in the system performance and its eventual failure.

Environmental safety

Under the UK Environmental Protection Act 1990, and similar regulations in other countries, it is an offence to negligently release refrigerants into the atmosphere. It is therefore a duty for a manufacturer to take all reasonable precautions to prevent the refrigerant from leaking. The British Standard BS4434:1995, 'The Safety of Refrigerants', specifies that all systems shall be leak tested prior to charging. This can be done by charging the system with an inert gas (dry nitrogen or helium) to 1.1 x the Maximum Working Pressure and checking each joint with a leak detector.

Safety

To ensure the safety of the refrigeration system any leak that could allow a build up of refrigerant to a dangerous concentration should be detected and repaired. A dangerous level of R600a is 20% of the Lower Explosive Level LEL. The LEL for R600a in air at sea level is 1.85%, so the maximum concentration that can be allowed is 0.37% by volume. If the leak were into a confined space, such as under a kitchen work-top, with a very low air change rate, less than 1 air change per week, then the maximum leakage rate would be 0.09 g/day or 32 g/year.

Reliability

A leak from a hermetically sealed refrigeration system should be small enough such that its performance will not be significantly affected during its lifetime. For a small system that is charge sensitive, the leakage should be less than 5% of the charge. For a charge of 25g over a life of 10 years, the leakage rate must therefore be less than 0.125 g/year. For a larger system, the maximum allowable leakage rate will increase in proportion with the charge.

Methods of leak testing

There are several different methods for leak testing. Some are more appropriate to use in the manufacturing process and some more for in field service. Traditional methods rely on the detection of gas passing through holes. These use bubble techniques and do not rely on the nature of the gas. They detect large leaks and show their position. However, a bubble test can only detect leaks larger than 10^{-3} to 10^{-2} mbar.l/s (100 to 1000 g/year of R600a). Smaller leaks require detectors that are more sensitive. Several of the electronic systems for detecting leaks rely on the presence of chlorine molecules in the refrigerant. These types of detectors, whilst suitable for R12, are entirely unsuitable for hydrocarbons. The smallest leaks are detected with helium in the system and using a mass spectrometer type sniffer to detect the leaks.

On the manufacturing line, leak testing can be carried out before evacuating the system and therefore tracer gases can be used in the system. The system is first filled with dry nitrogen to the maximum test pressure to which the system will be subjected to proof test the system. Large leaks can be detected by holding this pressure for a period of time or submersion in water tanks. The second stage of testing can be done under vacuum by evacuating the dry nitrogen from the system, totally dehydrating the system and testing that the vacuum can be held for a period.

The final method chosen will be a compromise between good refrigeration practice, the time available on the production line in which to carry out the tests and the size of leak that it is required to find.

On production Lines with a very high standard of work and where few leaks ever occur, it may be considered appropriate not to leak test the system at all and to rely on final refrigeration testing in order to pick up the presence of leaks.

Leak detection of hydrocarbon.

A halide torch (or any other detector using a naked flame) must not be used to detect hydrocarbon refrigerants.

Ideally, combustible gas detectors that are intrinsically safe should be used to detect hydrocarbons. Some existing electronic leak detectors will detect hydrocarbons, but the sensitivity may not be great enough, or may need adjusting. If the leak detector is not intrinsically safe then it must be switched on and off and calibrated in an environment where no hydrocarbons are present. These systems can detect leaks as small as 10^{-5} to 10^{-4} mbar.l/s (1 to 10g/year of R600a).

Leak detection fluids are suitable for use with hydrocarbon. The use of detergents with chlorine in should be avoided as the chlorine may react with hydrocarbons and corrode copper pipework. This method can only detect leaks as small as 10^{-3} to 10^{-2} mbar.l/s (100 to 1000g/year of R600a).

Oil additives, such as the Spectroline or Glo-leak fluorescent leak detection systems will work with hydrocarbon. While suitable for detecting small leaks in running systems, by their nature, they are not suitable for use on a production line as the system must run for a long period before the leak can be detected.

Helium leak testing is carried out by filling the system with helium to the test pressure and then testing the joints, and other vulnerable places, with a sniffer mass spectrometer leak detector. After testing, the helium is recovered as it is an expensive gas. If any helium does escape it is safe as it is a naturally occurring gas in the atmosphere. This method can detect leaks as small as 10^{-6} mbar.l/s (0.1g/year of R600a).

If a leak is found, don't assume it is the only one - check the whole system.

If a leak is suspected from a hydrocarbon filled installation, all naked flames should be removed or extinguished.

Leakage from plant which has been converted from CFCs or HCFCs

Alternative refrigerants, when used to convert CFC or HCFC plant, may sometimes leak where the old refrigerant did not. This is usually due to the different reaction with some seal materials, and possibly due to smaller refrigerant molecule size. Such leakage may also occur with hydrocarbon (although it is less likely), so systems should be leak tested after the hydrocarbon refrigerant has been charged into the system.

Hydrocarbon blends have been proposed as replacements for CFC and HCFC systems. As with all refrigerant blends, differential leakage may occur with blended hydrocarbons i.e. one component of the blend will leak in preference to the other component, thus altering the composition of the blend remaining in the system. The differential leakage will be most significant from parts of the system where the refrigerant is at its saturated conditions.

Repairing leaks

If a leak is found which requires brazing, the entire refrigerant should be recovered from the plant or isolated in a part of the system remote from the leak. Dry nitrogen should be purged through the lines being brazed to prevent oxides forming inside the pipes - a reaction which will cause subsequent damage to the compressor. This is good practice with all refrigerants, but elimination of the refrigerant is particularly important with hydrocarbons.

Recovery and disposal of hydrocarbon.

Under the UK Environmental Protection Act 1990, section 33, it is illegal to dispose of controlled waste in a manner likely to cause a hazard to human health or the environment. Any refrigerant would be classed as a controlled waste if it were deliberately vented into the atmosphere. It is therefore illegal to deliberately vent contaminated hydrocarbon refrigerants into the atmosphere. The Institute of Refrigeration publishes guidelines differentiating between deliberate venting and unavoidable loss.

Many recovery machines can be used with hydrocarbons. The major point to check when using a new recovery machine is that it does not use seals which are made of natural or silicone rubber and that any associated electrical components are sealed to prevent ignition in the case of a leak.

Dedicated hydrocarbon recovery cylinders should be used.

Dryers

Filter dryers should always be used in refrigeration systems. These remove any water and solid particles in the system and so ensure a long system life.

The Effect of Different Refrigeration Properties on System Performance

There are many ways in which to compare refrigerants. The foregoing discussion of the comparison of the properties gives little insight into the thermodynamic performance of refrigerants when used in a real refrigeration system.

A refrigeration system is essentially very simple. It consists of four components connected together with piping. These components are the evaporator, the compressor, the condenser and a restriction or expansion device. Of these, normally only the compressor contains moving parts. It is therefore surprising that in such a simple system it is so difficult to predict accurately how it will perform in practice. The reason for this is that the system operates at a fine balance point. Any small change in the system design will lead to a new operating or balance point for the entire refrigeration system. Sometimes surprisingly small changes can lead to quite large changes in system performance.

On the other hand, refrigeration systems are very robust. Almost any system of condenser, compressor, expansion device and evaporator connected together in the correct order and filled with almost any refrigerant will produce a refrigeration effect. It is therefore easy to produce a refrigeration system and many have been produced throughout the world with very little care or attention to detail. However, it is extremely difficult to optimise the performance of that system so that, for minimum cost, we can obtain maximum performance in terms of the temperature control of the refrigerated space and the amount of energy used to maintain it.

The Theoretical Cycle

A refrigeration cycle, commonly used in domestic refrigerators, is shown in Figure 1 and the numerical data for R12 and R600a in Table 2. The cycles compared are ideal. They assume that the refrigerant passes from the condenser with a fixed amount of subcooling into the capillary tube and that expansion in the capillary tube is without suction liquid heat exchange or any heat transfer to the surroundings. The enthalpy of the liquid gas mixture entering the evaporator is therefore the same as the sub-cooled liquid entering the capillary tube. The refrigerant leaves the evaporator with a steady 5K of superheat and there is no pressure drop between the evaporator and the compressor. However, there is a temperature increase due to heat pick-up in the suction line and compressor housing before entering the compressor port. It has been assumed that there is no pressure drops through the compressor valves.

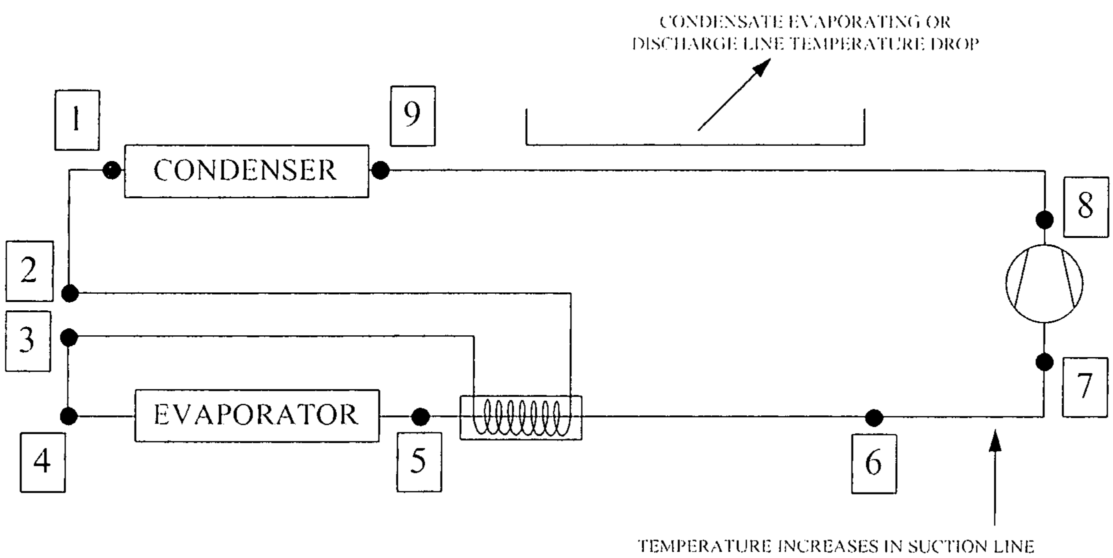


Figure 1 - The Refrigeration Cycle

Table - 2 Numerical Data for The Theoretical Refrigeration Cycle

Refrigerant		R600a	R12
Evaporator duty	kW	1	1
Condensing Temp	°C	40	40
Suction Temp	°C	varies	varies
Liquid subcooling	°C	1	1
Superheat at evaporator exit	°C	0	0
deltaT suction-liquid heat exchanger	°C	varies from10 to 0	
Pressure drop in suction line	bar	0	0
Temperature increase in suction line	°C	varies from5 to 0	
isentropic efficiency of compresser		0.7	0.7
Vol efficiency of compresser		0.8	0.8
Mechanical efficiency of compresser		0.7	0.7

One of the differences between R600a and R12 cycles is the pressure ratio. This is greater with R600a. This affects the expansion device, which has a larger pressure difference across it with R600a. A given expansion device will therefore pass less refrigerant from the high pressure to low pressure side at the operating point and may need adjustment when converting a system from R12 to R600a.

The pressure ratio also affects the work done in compression and this is therefore more with R600a but is compensated for by the lower inlet density.

The following Figures show a comparison between the displacement needed for R12 and R600a and the effect on COP of the cycle when volumetric efficiency and suction line pressure loss are varied.

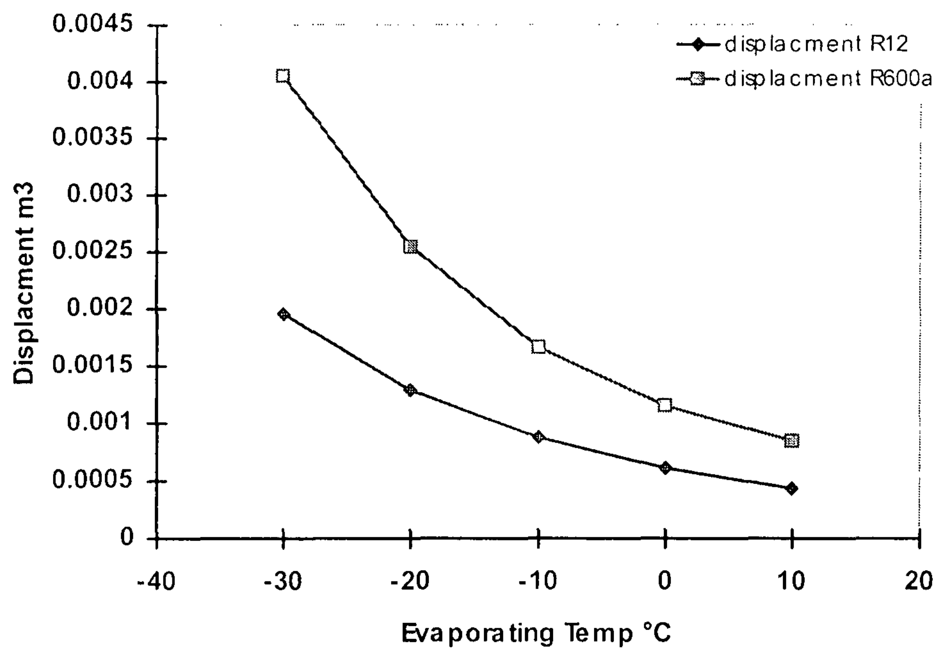


Figure 2 Comparison of compressor displacement for R12 and R600a for 1 kW cooling at 40°C condensing temperature.

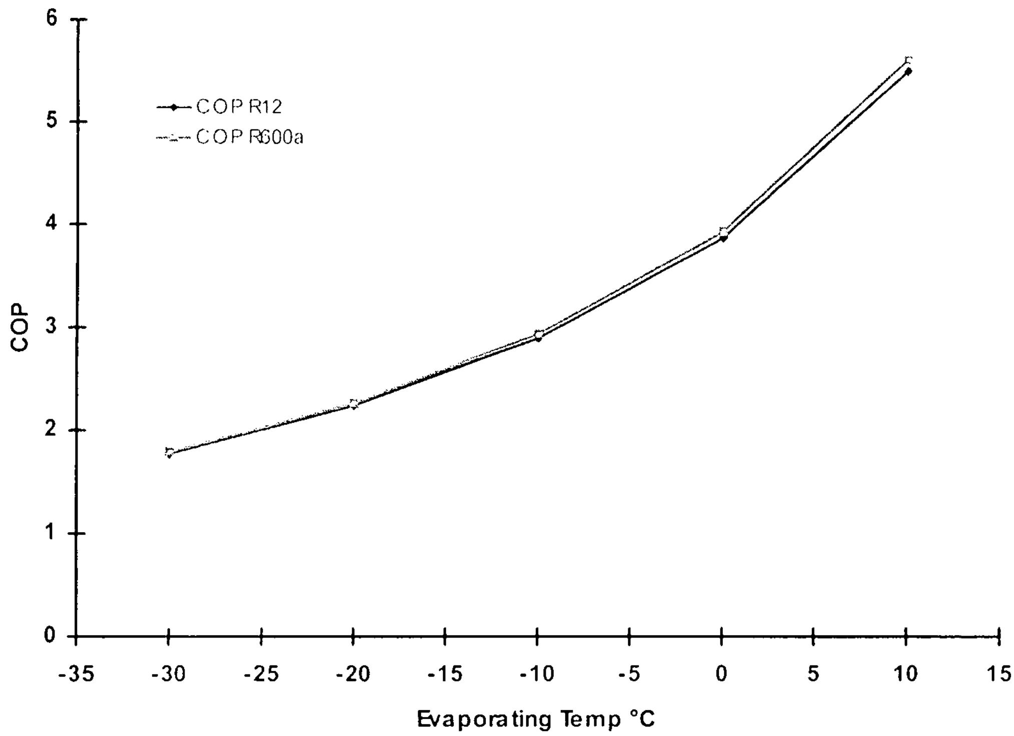


Figure 3 Comparison of COP for R12 and R600a condensing at 40°C.

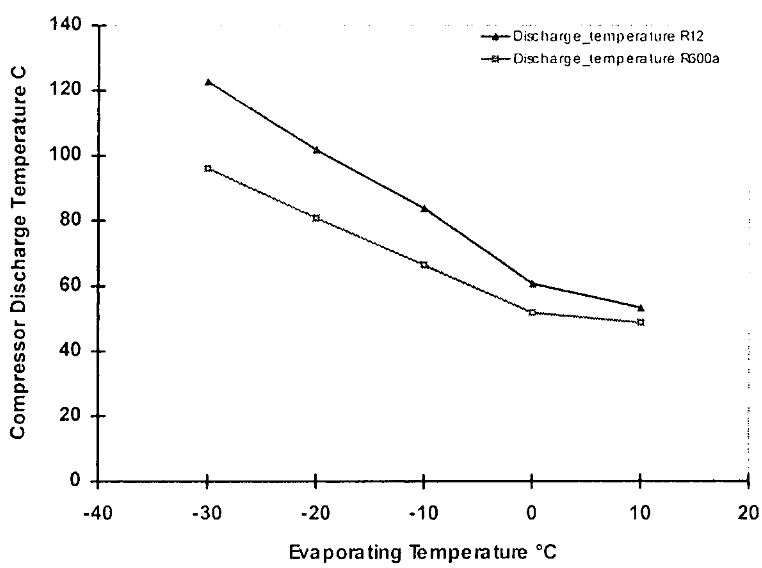


Figure 4 Comparison of compressor discharge temperature for R12 and R600a condensing at 40°C.

If an existing refrigerator has been converted from R12 to R600a then a different compressor has to be fitted. Although R12 compressors are suitable for use with R600a as a refrigerant without changing the oil or the components of construction, the displacement needed for the same refrigeration duty is considerably greater with

R600a than with R12. Figure 2 shows that the displacement for the R600a compressor needs to be double that for the equivalent R12 machine.

Figure 4 shows the comparison of the coefficient of performance for R12 and R600a with the above example. The performance is almost the same.

The discharge temperature for R600a is considerably less than that of R12.

Compatibility of hydrocarbons with system components and oil

Hydrocarbons are compatible with most of the materials that are used in CFC and HCFC refrigeration systems. This includes the oils, the metal components, compressor motor materials and most of the seal materials. The only materials that hydrocarbons are not compatible with are natural and silicone rubbers. These materials should not be used in systems with hydrocarbons.

The compatibility of hydrocarbons and system components must be compared in the presence of the lubricating oil. This is because the oil can play a major part in the interaction between the refrigerant and the components. We must also consider the operating temperatures of the system. For instance, a trace of a particular oil used in the manufacture of the compressor can pass into solution in the oil in the high temperature side of the system. This, when passed through the low-pressure part of the system, comes out of solution at the low temperature, creating a waxy deposit. If the comparison is made without the presence of the oil then this potential source of deposit in the capillary tube will not be detected.

There are a wide range of process chemicals and materials used in refrigeration systems. These include turning and assembly lubricants, wire winding lubricants, screening inks etc. Test methods looking at the interaction between the refrigerant and the lubricant and a number of the process chemicals and materials of construction have been devised and can be used if there is any doubt of compatibility.

Oil-refrigerant compatibility

R600a is fully miscible with mineral, alkyl benzene and ester oils. It can therefore be used with compressors designed for all other refrigerants.

The majority of domestic refrigeration systems have been designed to use oils which are completely miscible with the refrigerant and will thus be taken round the system with the refrigerant and returned to the compressor crankcase.

Limits on the maximum amount of contaminants that can be allowed in hydrocarbon systems

Table 3 shows the maximum recommended amounts of moisture, acidity, non-condensable gases, particulates and solubles which Copeland consider should be included in domestic refrigeration systems. They have consistently found that the inclusion of a filter-dryer in the system gives a significant reduction in problems due to contaminants throughout the life of the system. Therefore the use of filter dryers is strongly recommended.

Contaminant	Effects	Counter measures	Specification	Reference Documents
1. Moisture	1.1 icing in orifices 1.2 acid formation	1.1 Dry components 1.2 Filter drier	Refrig 10ppm Lubricant 50ppm System 300 mg	ARI 700-93
2. Acidity	2.1 corrosion	2.1 Clean components 2.2 Filter drier	Refrigerant 1ppm Lubricant 0.15 TAN	ARI 700-93
3. Non-Condensable Gases	3.1 higher pressures 3.2 higher discharge temperatures 3.3 Performance loss	3.1 Proper evacuation	Refrigerant 0.5%	ARI 700-93
4. Particulates	4.1 abrasive wear 4.2 orifice plugging 4.3 valve failure	4.1 Clean parts 4.2 Filter drier 4.3 Inlet screens 4.4 magnetic plug in compressor sump	Varies (20 to 40 mg in compressors)	Manufacturer's Data Sheets
5. Insolubles	5.1 expansion device malfunction	5.1 avoidance of incompatible chemicals	Varies (20 to 40 mg/sq-m)	Manufacturer's data sheets (eg: copper tubing; 3.5mg/sq-ft ASTM B280-88)

Table - 3 - Maximum Recommended Amounts of Contaminants in Domestic Refrigeration Systems. From a paper by S G Sundaresan, Proceedings Institute of Refrigeration London 1997/98

Redesign of refrigeration systems with R600a as the refrigerant

As can be seen from the preceding discussions, R600a is generally suitable as a replacement for R12 with the exception that a compressor with a larger displacement must be used. A starting point in the redesign of equipment for use with R600a is therefore to use the existing design of system but with a compressor with twice the displacement. The complex interaction of the parameters affecting the performance of refrigeration systems means that the laboratory tests must always be compared with R12 and the results carefully interpreted (see later).

In particular, the design of the capillary tube is especially important. This provides a restriction to the flow of refrigerant from the high to the low-pressure side of the system and has a strong impact on the overall performance. The pressure ratio between the high and low side of R600a systems is generally significantly greater than with R12 systems. Therefore, it is to be expected that the capillary tube will need to be shortened. As in the design of present systems, there are no reliable methods of accurately sizing the capillary tube for optimum performance by calculation alone.

The testing of designs using R600a is therefore very similar to the testing and development of R12 systems where the length and diameter of the capillary tube must be adjusted empirically in order to obtain optimum performance.

The speediest way of optimising the performance of the system is to proceed in a stepwise fashion. First, test the cabinet, then analyse the results, then make the improvements and then retest the system. Depending on the results of the retest, further iterations may need to be carried out until the optimum performance is obtained. The number of iterations is affected by not only the technical expertise and experience of the development staff but also by commercial considerations such as how much time is available and what is the acceptable level of performance for the intended market.

As much information as possible should be obtained during the test of the refrigeration system. In general, temperatures and pressures can be measured at most points in the system. Pressure transducers are connected to the suction and discharge sides of the compressor and, if the suction line pressure drop is likely to be substantial, an additional transducer is required at the discharge from the evaporator. Temperatures should be measured at all points in the system, at the beginning and end of each component. This is done by measuring the outside temperature of the pipe with thermocouples. There is only a small error (< 0.5°C) if the measuring points on the pipes are well insulated. It is also useful to measure the temperature in the evaporator and the condenser a short distance from the entrance and exits of these components. This is because there are many effects that influence the temperature, particularly at the entrance to evaporator and discharge from the condenser where sonic velocities at discharge from the expansion tube and the backing up of liquid in the condenser can significantly alter the readings and the interpretations of them. It is also useful to know what the mass flow rate of refrigerant is. However, this is almost impossible to measure in a domestic refrigeration system. The reason for this is that the inclusion of a mass flow meter, accurate enough to measure the flow rate, will significantly increase the volume of the refrigeration circuit. The volume of the refrigeration circuit has a significant effect upon performance of the system, therefore the measurement of mass flow rate is not possible in practice. Most refrigerant testing of small-scale domestic refrigerators is done with only an estimate of the mass flow rate based on the manufacturers data for the compressor. If such data is not available, and the mass flow rate is needed, then compressor tests must be organised, usually with the compressor manufacturer. In order to obtain this compressor data, it is not attached to a refrigeration system, which is influenced by the inclusion of a mass flow meter. Most refrigeration compressors are tested using an all gas cycle, without condensing the refrigerant vapour before returning it to the suction side of the machine by re-evaporating it.

The refrigerators are then set up in controlled test room conditions and all measurements are recorded on to a data logging system. These are checked until stable operation is obtained. At this point, a set of readings is made over a significant period; including a complete defrost if this is appropriate. The data is then downloaded from the data capture system, plotted onto graphs and analysed.

In countries that have already converted to R600a, the conversion from R12 to R600a has coincided with a move to reduce the energy consumption of refrigerators per unit volume. At first sight, replacement with R600a would appear not to alter the energy consumption. However, the original design of system using R12 would not necessarily have been fully optimised for energy consumption. There are a number of improvements that can be made to the design of the refrigeration system, and to the design of the cabinet, which will improve the energy consumption. The necessity of meeting the market demand for lower energy consumption in refrigerators has forced manufacturers to spend more time, and in some cases more money, on the development and manufacture of their refrigerators in order to meet the new market conditions. Therefore, refrigerators now being sold with R600a generally use less energy than the systems they replace.

There are a number of ways in which the refrigeration system can be optimised. In vapour compression systems, the smaller the temperature difference between the high and the low-pressure sides of the system the lower the energy consumption. Therefore by using larger evaporator and condenser surfaces, so that the temperature difference between the refrigerant and the air is reduced, the temperature difference between the high and the low side can also be reduced thus leading directly to reductions in energy consumption.

There is a complex interaction between the operation of a refrigerator thermostat, the length of time for which the compressor runs and the lowest temperature to which the refrigeration system will reduce the air. In systems in which the cut off point of the thermostat approaches the lowest temperature to which the refrigeration system will reduce the cabinet, there is a long run time before the compressor will eventually switch off. This long run time, without a corresponding increase in the off cycle time while the temperature in the cabinet increases again back to the cut in temperature, means that the total energy consumption of the cabinet is greatly increased. By making very small changes to the system, enabling the system to pull down to lower temperatures, the run time of the compressor can be reduced, thus giving a considerable saving in energy consumption with only a small increase in the average temperature of the refrigerated space.

The development and testing of small refrigerator circuits.

Tests for proving system performance and development have different objectives. Performance testing of a refrigerator is only carried out to measure its performance. Development testing is carried out to gain additional information to see why the performance is what it is, or why it is not performing in the way that is expected, so that an improvement can be made.

There are therefore 2 types of test.

- A development test where we are interested in performance by comparison with the desired performance defined by a set of objective criteria. In the case of conversion of an existing refrigerator operating with R12, the criteria are its current performance. This must therefore be measured as well as the performance with the hydrocarbon refrigerant. Additional information must also be measured so that the reason for the performance can be analysed. These tests are comparative and do not necessarily have to be carried out under standard conditions.
- Testing an already developed refrigerator is carried out to provide users with objective information on its performance so that they can compare it with other

refrigerators. These tests must therefore all be carried out under the same conditions. The ISO standards set out the test conditions for domestic refrigerators.

All tests should have a clear objective. The method can then be worked out, the results are then tabulated and then these results are processed and interpreted. The process will normally entail one or more graphs of temperatures plotted against time, in order to show the pattern that the temperatures move in and their relationship with each other, and one or more tables, typically of averaged temperatures, from which conclusions can be drawn. The conclusions should reflect the objectives of the test and clearly state whether these objectives were met or not. Each test should have a test report, even if it is only a short report on one side of paper, giving a clear account of the above.

The order of tests for the redesign of refrigerator circuits are:

Test	Reason for test
Pull-down and continuous running	Development
Storage temperature (ISO) at maximum climate condition	Development and ISO
Storage temperature at minimum climate condition	Development and ISO
Energy consumption	Development and ISO
Other ISO tests.	ISO

A pull-down and continuous running test is a quick test, carried out to measure the coldest temperature achieved and the time taken to reach 90% of the temperature reduction in the maximum ambient that the refrigerator will operate in. These values are then compared for the R12 and hydrocarbon machines. Experience has shown that if the results for R600a are as good or better than R12, generally all further tests will also be the same or better. However, it is important that the experience of measuring this is obtained first; therefore, additional tests must be carried out.

Measurement of the storage temperature at the maximum temperature conditions is an ISO test and should be at the ST or T climate rating (sub-tropical or tropical) for refrigerators sold in China. The refrigerator should cycle under control of the thermostat to give a maximum temperature in the test packs of -18°C. In order to achieve this it is necessary for the room to be stabilised and the thermostat to be adjusted such that the minimum run time is obtained in order to achieve -18°C at the maximum point. This test is then repeated on the same refrigerator with R600a.

For the development of refrigerators normally only the first 1, 2 or maximum 3 of the above tests need to be carried out. As long as comparable tests are also made on the R12 refrigerator, in order to establish the performance of the R600a refrigerator is the same or better, no additional tests need to be made as to performance. However, if a new refrigerator is being developed then full performance testing must be carried out according to the ISO standard in order to satisfy all potential customers.

Test method

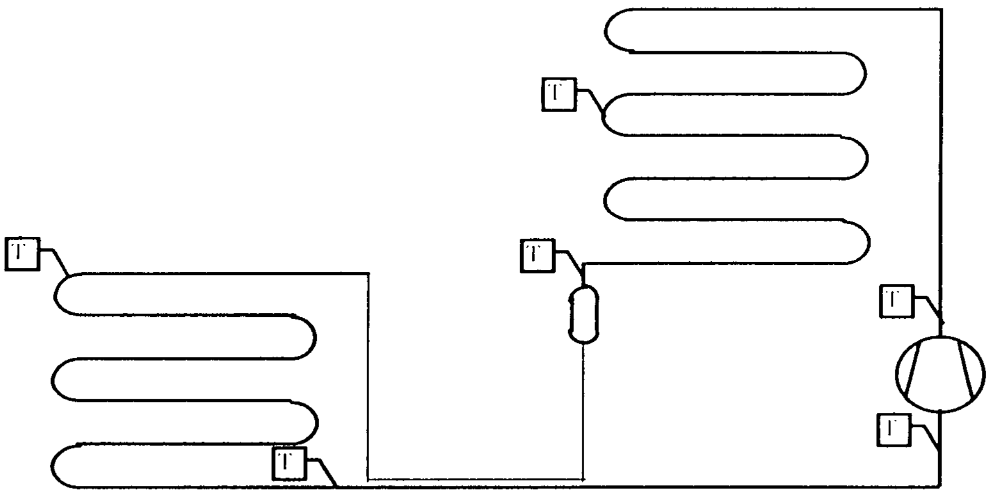


Figure 5 Diagram of a refrigeration circuit showing where refrigerant temperature should be measured

The following measurements should be made for the redesign of refrigeration circuits for R600a. The ambient temperature, evaporator, condenser, suction and discharge temperatures and the temperature at the entrance to the capillary tube and at the exit from the evaporator (Figure 5). For development, comparative performance can be measured by measuring the air temperature at one point in the refrigerator or freezer compartment. The purpose of these measurements is to be able to measure the amount of sub-cooling at the exit from the condenser before the entry to the capillary tube and to measure the amount of superheat at the exit from the evaporator.

For pull-down tests, the freezer and/or refrigerator compartments must be empty. For other tests, the freezer compartments must be loaded as specified in the ISO standard and the refrigerator compartments remain empty. For continuous running the ambient conditions should be the hottest for which the refrigerator is designed and the thermostat bypassed to force continuous operation of the compressor.

Interpreting the results

From the measured results the sub-cooling at the entrance to the capillary tube and superheating at the exit of the evaporator are calculated. The following can be used as a guide to system performance:

- If the sub-cooling is greater than 2°C and if the superheat is greater than 3°C, the capillary tube is too long, restricting the flow of refrigerant at these operating pressures and starving the evaporator of refrigerant.
- If the subcooling is greater than 2°C and the superheat is between 0 and 2°C, the charge is too large.
- If the subcooling is approximately zero and the superheat is greater than 3°C this indicates that the entire circuit is short of refrigerant and the charge is too small.
- If the sub-cooling is approximately 1-2°C, the superheat is approximately zero and in addition the temperature of the suction to the compressor is considerably less

than normal then the capillary tube is too short. The normal temperature of the suction must be obtained from the R12 machines. This temperature is normally approximately 30°C.

The enthalpy difference across the liquid / suction line heat exchanger in the capillary tube per unit mass of refrigerant flowing round the circuit is approximately the same as the enthalpy increase in the suction line across the same heat exchanger. This can be used to investigate the temperature at the compressor suction. If this is excessively cold, it would indicate that a large quantity of liquid was leaving the evaporator unevaporated. The phase change in the suction line occurs at constant temperature so the temperature will not increase until all the liquid has evaporated.

Conclusions

Does the refrigerator / freezer achieve the same or colder temperatures as the criteria temperature, and in the same time? If yes, then performance is as good as or better than the criteria. If no then why? What action is needed to improve the performance?

The design of new refrigeration systems

The design of a new refrigerating system starts with the operating temperatures needed on both the low and the high-pressure side and the load profile. For refrigerator cabinet and freezer design, these conditions are set by the test conditions for the market for which the refrigerator is intended. The load is therefore considered constant with time.

When in use the domestic refrigerator or freezer has a wide range of loads. Take the following scenario for example.

A refrigerator is in a cold kitchen overnight. During this time the door is closed, all the food is already cold and the ambient temperature is very low. Therefore the load is very low. However, it does have some load and the refrigerator needs to operate to maintain the temperature of the food. In the morning, the house heating starts and the temperature in the kitchen starts to increase. People get up, come into the kitchen, and open the refrigerator door. Some leave it open for periods of up to a minute whilst food is removed. The food is left out in the kitchen warming up. An hour later, the door is again opened and the warm food is placed back into the refrigerator. The load on the refrigerator is now very large. Warm food, which it was not designed to cool, has been placed inside it, the door has been open for long periods warming up the interior and the structure of the refrigerator and the ambient temperature in the kitchen is high.

We can thus see how a real refrigerator has in fact got to work over a much wider load range and ambient temperature conditions than the test room conditions for which it is primarily designed.

To design a new system it is still necessary to consider the maximum instantaneous load on the refrigerator, the temperature in the cabinet and the temperature of the ambient air. The first task is to select or design the evaporator. This will then dictate what the evaporation temperature of the system must be. Next, suction line heat gains and pressure drop must be added. The condenser is selected next. At this point, we must assume what the heat gain is going to be in the compressor that must then be removed by the condenser, in addition to the load from the evaporator and the suction line. Selecting or designing the condenser will fix the condensing pressure and hence the discharge pressure for the compressor.

The next step is to select the compressor. We now know the suction pressure, delivery pressure and the load in terms of the mass flow rate of refrigerant and the volume flow rate at the entry to the compressor. This will primarily be a case of selecting a compressor that will cope with the pressure ratio, and with the design swept volume, taking into account the volumetric efficiency of the machine. It is now necessary to check that the design of the condenser is in fact adequate to remove the actual heat gain from this compressor. This may involve an iterative process whereby the condenser is resized and a new compressor is selected. Once the condenser and compressor have been selected to work with the evaporator, the final task is to size the capillary tube.

The capillary tube is notoriously difficult to design and every capillary tube is in practice designed empirically. Therefore experience and/or the models that are available for capillary tube sizing are only used in order to select the first guess at capillary tube diameter and length.

The diameter of the capillary tube is important. If it is too small, it will be prone to blockage and will require a higher specification of cleanliness in the refrigerant and the refrigeration system components. Many factors also govern the length of the tube. If the tube is too long then it is very difficult to contain it easily within the cabinet and long tubes are prone to damage during the manufacturing process. Similarly, too short a tube will create difficulties in connecting the condenser with the evaporator and may involve the inclusion of additional lengths of tubing which will have an effect on the system performance. There are therefore limits on both the diameter and the length of the tubes that can be used and the two must be juggled together in order to give the correct refrigerant flow rate.

Some thought must be given now to the operation of the system when it is not at design condition i.e. when the condensing temperature and hence the discharge pressure from the compressor is considerably lower than the design. When the system switches on, although it may run for a shorter period and/or less frequently it is still necessary to have sufficient pressure difference across the capillary tube in order to work satisfactorily. Sufficient liquid must be transferred from the evaporator to be backed up in the condenser to increase the pressure and hence the refrigerant flow rate through the condenser. Many refrigerators cease to operate effectively when operating at a very low temperature difference between the evaporator and the condenser. It is important to check that the capillary tube will offer sufficient resistance. The main way of doing this is to ensure that there is sufficient refrigerant charge in the system for the refrigerant to back-up in the condenser under these conditions, thus artificially raising the condensing pressure and maintaining the flow of refrigerant through to the evaporator in order to ensure satisfactory operation of the compressor.

The system must then be assembled and tested. At this point the procedure is very similar to that for the redesign of an existing system in which an existing design of R12 refrigerator is redesigned for use with R600a.

The development of Refrigeration Systems

As much information as possible should be obtained during the test of the refrigeration system. The principal thing that we are looking for in the results is the pattern of fluctuations of temperature in the system. After a number of tests have been conducted, these start to fall into repetitive patterns and the interpretation of the data becomes easier. Any deviation from the standard patterns must be explained in terms of the phenomenon that causes it. The reasons for deviations from standard patterns are not always obvious and form the main backbone of this assistance programme in the redesign of refrigerators to use alternative refrigerants.

Table 1 Refrigerant Property Comparison R600A V R12

		R600a	R12
CHEMICAL FORMULA		$CH(CH_3)_3$	$CCl_2\ F_2$
Molecular Weight		58.1	120.9
Boiling Point at 1 atm	°C	-11.7	-28.9
Freezing Point	°C	-160	-158
Critical Temperature	°C	135	112
Critical Pressure	bar	36.45	41.15
Critical Volume	m^3/kg	.004526	0.00179
Specific Heat of Liquid at 30°C	kJ/kg/k	2.49	0.99
Specific Heat of Vapour at 30°C	kJ/kg/k	1.86	0.62
Ratio of Specific Heats at 1 atm 30°C		1.10	1.136
Density of Liquid at 30°C	kg/m^3	545	1292
Density of Saturated Vapour at Bpt	kg/m^3	2.81	6.30
Latent Heat of Vaporisation at Bpt	kJ/kg	362	165
Latent Ht of Vapour at Bpt/m3 vapour	kJ/m3	1017	1039
Thermal Conductivity Liquid at 20°C	W/m/k	0.098	0.0727
Thermal Conductivity Vapour at 30°C	W/m/k	0.017	0.010
Viscosity of Liquid at 30%	cP	0.14	0.19
Viscosity of Vapour at 20°C	cP		0.0127
Surface Tension	kN/m	8.6	9.0
Solubility in Water at 30°C 1 atm	%wt		0.028
Solubility of Water in Refrigerant at 20°C	%wt		0.009
Vapour Pressure at 25°C	bar	3.5	6.516

FOOD REFRIGERATION
AND PROCESS
ENGINEERING
RESEARCH
CENTRE

Refrigerator Design and Energy Optimisation.

Andrew Gigiel

Food Refrigeration and Process Engineering Research Centre
University of Bristol Langford Bristol BS40 5DU UK
44 (0)117 8289251 Fax 44 (0)117 9289314 e-mail frperc-bris@bristol.ac.uk

Introduction

The purpose of a refrigerator

The purpose of a refrigerator is to keep chilled food as close to 0°C as is possible, without freezing it, to keep other foods which do not need to have a very cold storage temperature at varying temperatures between zero and the ambient. The purpose of a freezer is to keep frozen food at temperatures between -8 and -18°C depending on the expected storage life of the food.

The refrigerator is mainly used in the kitchen in a home or in a business. Some are also used for keeping drinks and ice creams cold when on sale in the street.

In order to use a refrigerator food must be kept in it, other foods sometimes warm, sometimes pre-cooled, can be added to the refrigerator and food maybe removed. In order to achieve this the door or lid must be opened and closed. On occasions, the door is left open for longer periods.

All this should be accomplished with the smallest amount of space necessary and with the smallest amount of energy consumption at a cost the consumer can afford.

Difference between Standard tests and use

The way a refrigerator or freezer is actually used is very different from the way that it is tested according to national and international standards. The main purpose of these standards is to be able to make comparisons between one refrigerator and another and to be able to enforce minimum standards of performance. The standards have mainly been devised by refrigerator manufacturers with very little input from users. As a result, during Standard tests you are not allowed to open the door, you cannot keep food in the refrigerator and you certainly cannot add warm food to them.

Designers should therefore keep in mind that although the performance of the refrigerators that they are designing will be tested to national and international standards, ultimately the user will apply a very different standard to the finished product. If users are to come back and buy more of these refrigerators, both standards and the requirements of the user must be satisfied.

The task of the designer

It is the task of the designer to satisfy these various needs. The refrigerator or freezer must work in people's homes or businesses. It must meet the standards so that its performance can be compared on a like for like basis with other refrigerators. It must meet any legislation required and finally it must please the non-engineers in the company such as salesmen and executives who will make their own judgements on the design.

An empirical method of refrigerator design

An empirical design of a refrigerator does not start with a blank sheet of paper. It starts with the concept of the refrigerator that you, I and everyone else has. This concept is a model that exists either in reality or in the head of the designer. Not only is it in the head of the designer but it is also in the head of the legislator, the business executives within the company and above all the customer. If a refrigerator is designed that does not fit in with the concept that people expect, sales executives in the company will have a hard job convincing customers that this really is a refrigerator and that it will really do what you say it will.

The basic methodology is to take a refrigerator and see if it works. A test is performed on the refrigerator to find out if it works and how it works. From the measurements made it will be possible to make a judgement as to what does not work, why this particular aspect is not working and how it can be improved. This type of development is done in steps. In order to make a new design you must always keep in mind who will 'judge' your design. For example, ammonia is a very good refrigerant, easily available, very green, requiring low energy and cheap. However, end users and others in your company may be frightened to use this refrigerant. In addition, there will be no suitable components readily available to use with ammonia. Therefore, you need to take into account peoples perceptions of your design as well as its excellence at reducing energy consumption.

The refrigerator development therefore proceeds in steps making small improvements to each component and to each part of the refrigerator in turn. At the end of this process, the original tests are repeated and the overall performance assessed. It might still be necessary to start again a small series of improvements, one step at a time, in order to make further improvements.

This iterative process of empirical design is repeated until eventually the performance of the refrigerator is judged "good enough" for the market and to meet the legislative standards.

The advantage of this method of development is:

1) The refrigerator will always work.
2) Progress can be seen and quantified.
3) The process itself leads to creative thinking in a way that staring at a blank sheet of paper does not.
4) It is used by many designers throughout the world; it is a tried and tested method.

The disadvantages are:

1) Development proceeds only until the design is "good enough"
2) The optimum performance is never achieved.
3) The creative thinking process is linear, can run on lines. It does not allow for step changes to totally new concepts.
4) Improvement is only incremental. No giant leaps are ever taken.

5) It is very expensive as the process is very time consuming, taking many months from the start of testing until an improved design has been fully developed.

How to develop a refrigerator

A minimum of two models of the refrigerator are needed. One will be the original and be used to compare the results of the development, and the other will be developed into the new refrigerator.

A pull-down and continuous running test (no load) should be carried out on the original version of the refrigerator in the maximum ambient temperature for the climate class (32°C for class N). This will establish the evaporating and condensing temperatures that the refrigerator has been designed to operate with. The temperatures should be measured at the positions shown in Figure 2. To achieve this the refrigerator should have had temperature sensors fastened to the pipework during manufacture. Alternatively, some of the skin of the refrigerator and some of the insulation will have to be removed to gain access to the beginning and end of the evaporator, and possibly the condenser as well.

First one should chose the refrigerant. R600a is generally better than R134a (or R12). An initial compressor selection can then be made for the development. This will have a similar capacity to the original compressor when operating at similar temperatures. Not all compressors have the same efficiency (quoted as COP at standard operating conditions), therefore several different manufactures and models should be tried.

The capillary tube then needs to be selected. This is very difficult to do exactly by calculation. However, some compressor manufactures give guidance and there is now some literature available. The spreadsheet at the end of this section is based on the publication by Driessen et al and can be used to estimate the mass flow rate through a capillary tube under adiabatic conditions for refrigerants R134a and R600a. In this calculation the length and diameter of the proposed capillary tube and the thermal and transport properties of the liquid refrigerant at the entrance to the capillary tube are entered and the resulting mass flow rate calculated. However, this calculation is for adiabatic flow. Most refrigerators use heat transfer between the capillary tube and the suction line to enhance performance and prevent ice formation and condensation on the suction pipe. The capillary tube used on the original refrigerator is therefore normally the best guide for the capillary tube to start the development.

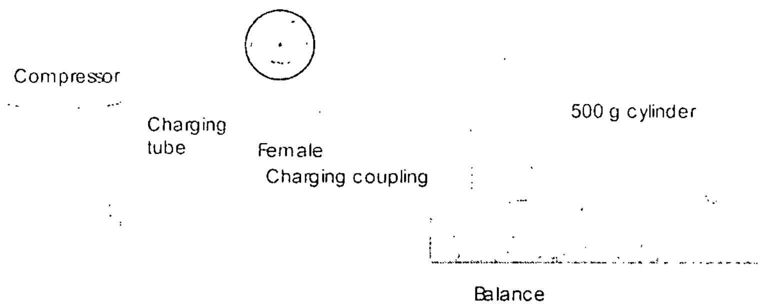
The mass flow rate is calculated from the compressor manufactures data for the compressor selected. It is the capacity divided by the refrigeration effect for the refrigerant at the conditions under which the capacity was measured (also calculated in Excel spreadsheet). Different lengths and diameters are then entered to find a suitable combination that will provide this flow rate.

Once an initial selection of capillary tube has been made, the calculated length should be increased (by perhaps 1 or 2 m depending on the calculated length) and this tube and the compressor installed in the refrigerator. At the same time, tapings with Schrader valves should be fitted in the suction and discharge tubes to the compressor.

The charge can then be optimised for this combination of compressor and capillary tube.

To optimise the charge of the refrigeration system the refrigerator is first connected to a refrigerant manifold. The system is pressure tested with dry nitrogen and then evacuated. Approximately half the expected optimum charge is then added. The charge should be transferred from the refrigerant bottle into the refrigerator system as a gas at a slow rate so as not to overcharge the system. If the refrigerant is a non-azeotrope and must be taken from the bottle as a liquid then it should be passed through a capillary tube before entering the system. The refrigerant bottle and associated equipment (charging hose, manifold etc.) is stood on a scales and the weight recorded before and after charging to calculate the mass of refrigerant charged into the refrigerator. The length of the charging hose should be kept to an absolute minimum.

An alternative charging system is as follows.



1 Use a small cylinder fitted with male and female quick refrigerator connectors.

2 Evacuate the cylinder.

3 Purge flexible hose on main refrigerant bottle.

4 Fill cylinder with the charge of refrigerant required.

5 Re-weigh cylinder to ± 0.1g.

6 Evacuate refrigerator circuit 2 times. On each occasion warm the compressor to remove refrigerant dissolved in the oil.

7 Connect cylinder to refrigerator with the cylinder upside down to charge the refrigerant as liquid.

8 Warm cylinder to remove all liquid refrigerant while running the refrigerator compressor.

The compressor is then started. When stable operating temperatures have been achieved, or sooner if the results are obvious, the temperature at the end of the evaporator is compared to the evaporating temperature and the temperature after the accumulator. The optimum charge is usually close to the point where there is no superheat at the end of the evaporator but a small amount of superheat after the accumulator.

If the system is undercharged, there will be superheat at the end of the evaporator. If the system is overcharged, there will be no superheat at the end of the accumulator, an increase in the amount of subcooling at the end of the condenser, an increase in the condensing temperature and a reduction in the compressor suction temperature.

If the evaporator temperature is not what is required (the same as in the original version in the first instance) then the capillary tube will need to be altered. It is always easier to start with a longer capillary tube than needed and shorten it, than to increase its length. To reduce the evaporating temperature a longer capillary tube is needed and to reduce the evaporating temperature a shorter capillary tube is needed.

To alter the capillary tube the refrigerant must be removed from the system. A refrigerant recovery machine should be used. This ensures that the refrigerant is not released to the atmosphere and the recovered refrigerant can be weighed to confirm the amount of charge added in the first place. The system is then filled with a slight over-pressure of dry nitrogen and the manifold disconnected.

Whenever the system is opened, as when the capillary tube is shortened, a new filter dryer must be fitted. When the alterations have been made the above process is repeated.

A storage test at the warmest ambient temperature for the climate class should then be carried out. This will show if there is a possibility of reducing the evaporator temperature. If during this test compressor run time is not near 100% and the warmest test temperature is not exceeded, then there is scope to increase the evaporating temperature. The warmer the evaporating temperature the less heat will enter the refrigerator and the COP of the refrigeration system will be greater. Therefore, the energy consumption will be reduced.

If the storage test shows that the evaporating temperature can be increased, then either the capillary tube should be shortened (or the diameter increased) or a smaller compressor can be fitted. In either case, the charge and capillary length will need to be reoptimised, and then the storage test repeated.

The energy consumption test can then be carried out. Both the original and the developed version should be tested and the results compared. If the development has been successful, the energy consumption of the converted refrigerator should be less than that for the original version. If it is desired to reduce the energy consumption still more, then other changes may need to carried out to the refrigerator involving the thickness of the insulation and the design of the evaporator and condenser (see below).

Reducing the energy consumption of a domestic refrigerator or freezer.

The refrigeration system

Reducing the condenser temperature and increasing the evaporator temperature.

The refrigeration effect is the amount of heat absorbed by the refrigerant in the evaporator. It is the difference in specific enthalpy between the refrigerant entering the evaporator and that entering the compressor, multiplied by the mass flow rate of the refrigerant. If the system is charged so that the refrigerant leaving the evaporator is saturated and saturated liquid enters the capillary tube then the refrigerant effect is as shown in Figure 1.

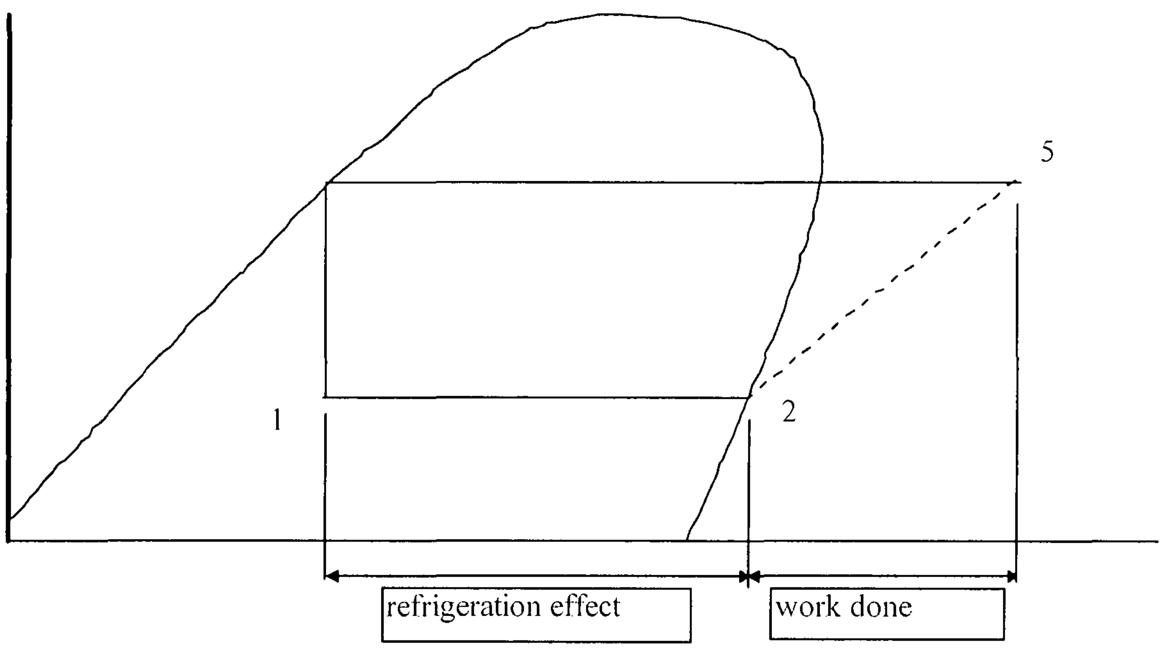


Figure 1 Pressure enthalpy diagram showing the refrigeration effect and the work done on the refrigerant. The numbers refer to the positions shown in Figure 2.

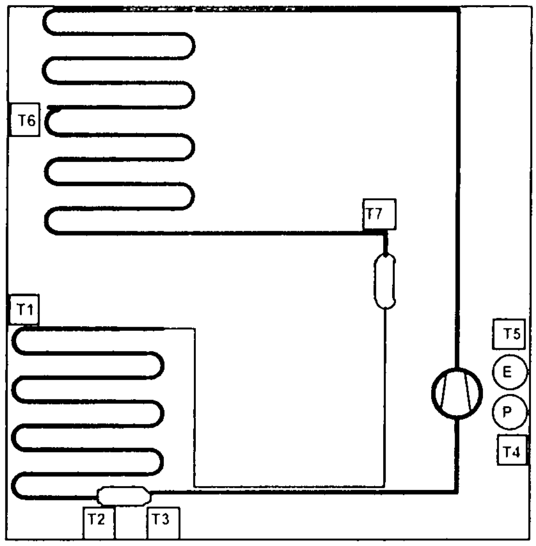


Figure 2 Refrigeration circuit diagram for a domestic freezer.

The coefficient of performance (COP) of the refrigerator is given by:

$$COP = \frac{refrigeration\_effect}{work\_done}$$

For minimum energy consumption, we require to maximise the refrigeration effect and minimise the work done.

If the evaporator temperature is increased then the refrigeration effect is increased and the work done is decreased (Figure 3).

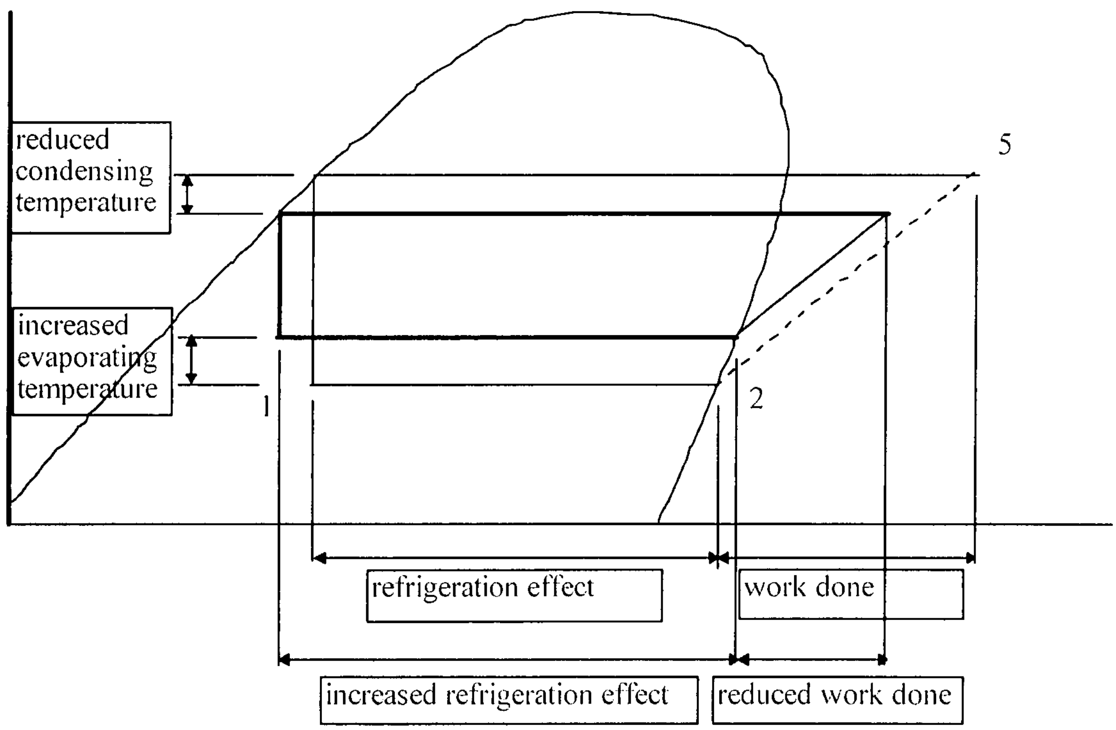


Figure 3 Pressure-Enthalpy diagram illustrating how the energy consumption of a refrigerator is reduced by reducing the condensing temperature and increasing the evaporator temperature.

The COP is therefore reduced and more heat will be extracted from the freezer with less energy consumption.

Suction liquid heat exchange

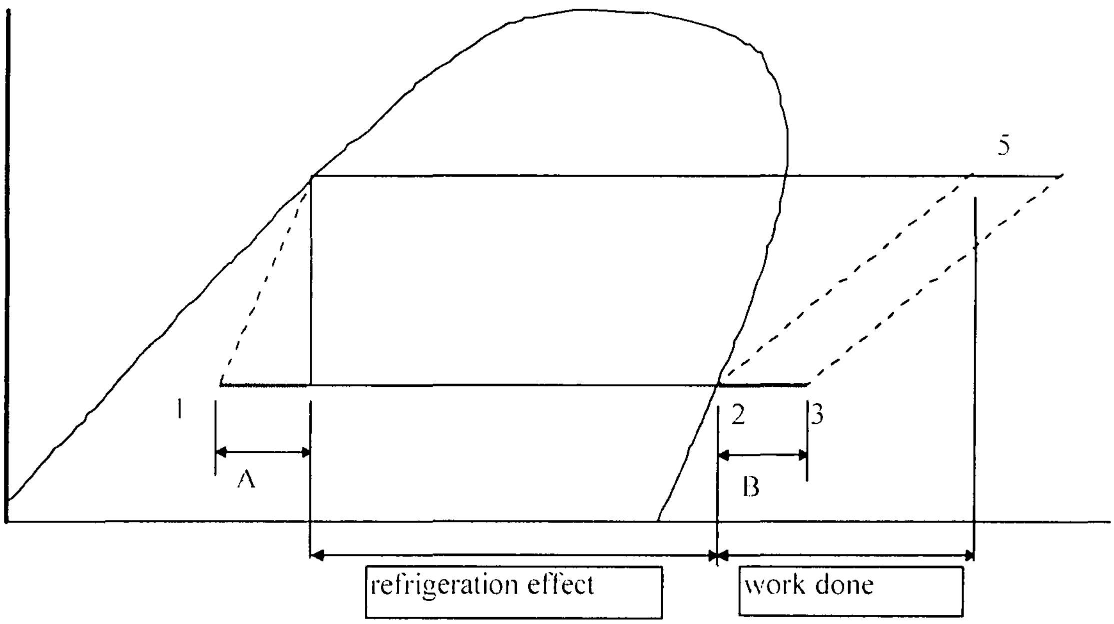


Figure 4 Heat exchange between the cold refrigerant in the suction line and the warm refrigerant in the capillary tube.

The refrigeration effect can be increased if point 1 is moved to the left on the p-h diagram (Figure 4). To do this warm refrigerant must be cooled, reducing its enthalpy. There is a source of cold available from the suction gas leaving the evaporator, which is at or near the suction temperature. The heat exchange is affected by bringing the capillary tube into good thermal contact with the suction gas in counter flow. The amount of heat leaving the capillary tube A is equal to the heat gain in the suction tube B.

The refrigeration effect is increased by A and the work done on the refrigerant remains approximately constant. The COP in therefore increased and the energy consumption reduced.

The limits of the improvement are:

- the liquid in the capillary tube cannot be cooled to less than the suction temperature.
- the suction gas cannot be heated to more than the condensing temperature.
- the temperature of the discharge from the compressor may exceed the acceptable temperature.
- the capillary tube will operate differently from an adiabatic capillary tube.

When the suction temperature is -23°C and the discharge temperature 45°C, the COP of a typical chest freezer can increase from 1.22 to 1.32 if heat exchange is used to increase the suction temperature from -23 to 40°C (Figure 5).

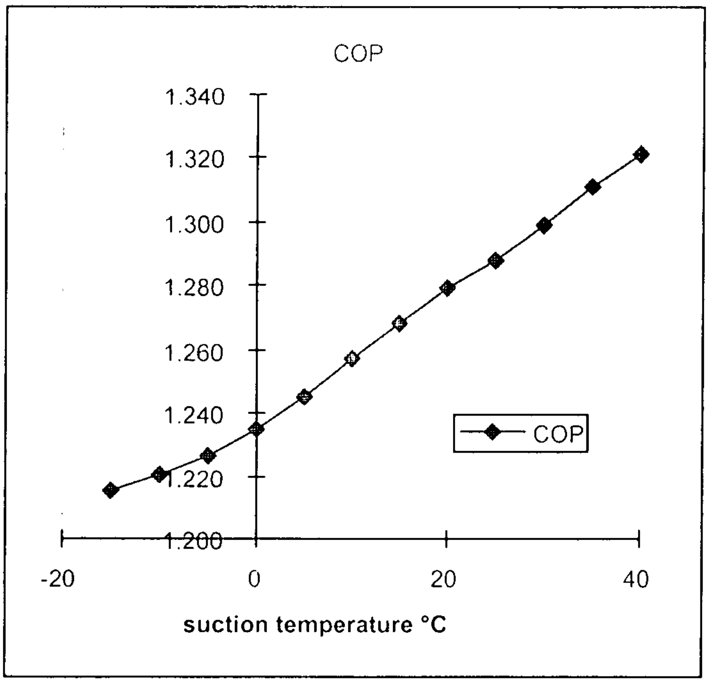


Figure 5 Improvement in COP as suction liquid heat exchange is increased from 0 to maximum (R600a suction temperature -23°C, discharge temperature 45°C).

Compressor isentropic efficiency

Ideal reversible compression (isentropic) uses the minimum amount of energy in a hermetic refrigeration compressor. In practice, the compression process is not reversible and more work is done on the refrigerant, increasing the temperature of the discharge gas and the amount of heat dissipated from the compressor case. This is shown in Figure 6 where point 5, the discharge from the compressor, moves to the right as the compressor becomes less efficient. The work done increases form a minimum of A as the isentropic efficiency reduces.

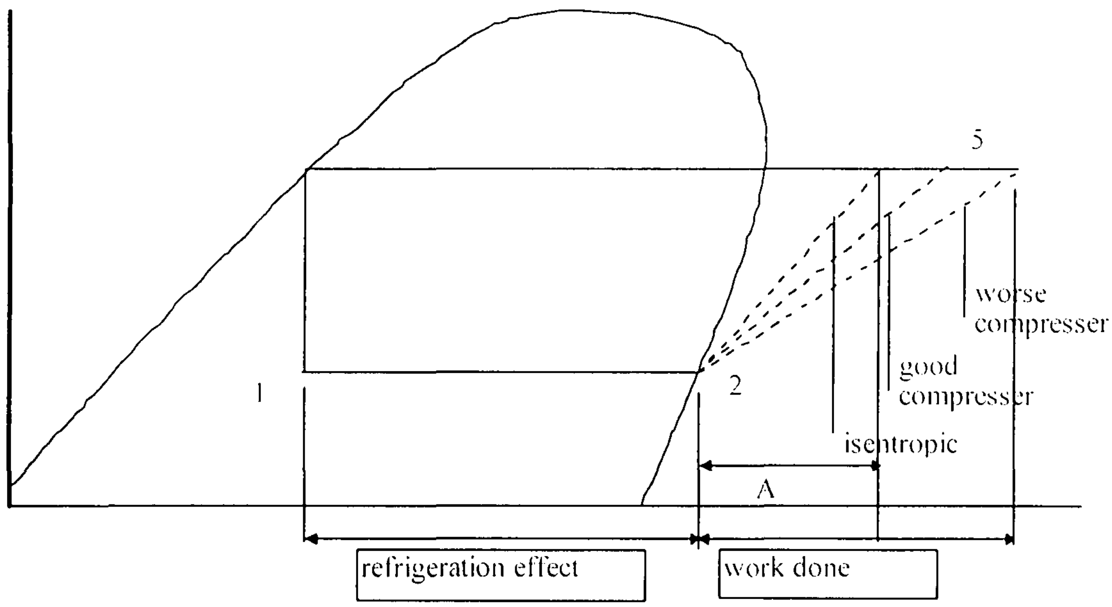


Figure 6 p-h diagram showing the effect of compressor isentropic efficiency on the work done.

The isentropic efficiency is defined as;

$$isentropic\_efficiency = \frac{work\_done\_in\_isentropic\_compression}{actual\_work\_done}$$

Not all compressors have the same efficiency. By fitting a compressor with a greater efficiency, the COP is improved and the energy consumption reduced.

In practice, isentropic efficiency is impossible to measure for a hermetic compressor. The efficiency is integrated with the compressor motor efficiency and given by manufactures as a 'COP' value where this COP is defined as:

$$COP = \frac{capacity}{electrical\_power\_used}$$

Energy consumption can be reduced by 25% by fitting an efficient compressor if the original compressor is of poor efficiency.

The freezer cabinet

The temperature of the cabinet is a result of the energy balance between the heat leaving the cabinet through the insulation and the heat extracted by the refrigeration system (the cooling load). If more heat enters the cabinet through the insulation than is removed by the refrigeration plant then the temperature will increase and visa versa. Unfortunately, the temperature of the cabinet is not uniform and the warmest temperature of the food must be -18°°C. In order to achieve this the evaporator temperature must be colder than -18°C. How much colder depends on the design of the cabinet and the effectiveness of the insulation.

Increase the insulation of the cabinet (U value)

The heat entering the cabinet must flow through the insulation. The heat flow will depend on the surface area, the thermal conductivity and thickness of the insulation as in the following function:

$$Heat\_flow = UA(T\_inside - T\_outside)$$

In a chest freezer the majority of the heat flow is through the insulation directly to the evaporator (Figure 7). Therefore, the heat flow will be reduced if the evaporator temperature is warmer since the temperature difference will be reduced.

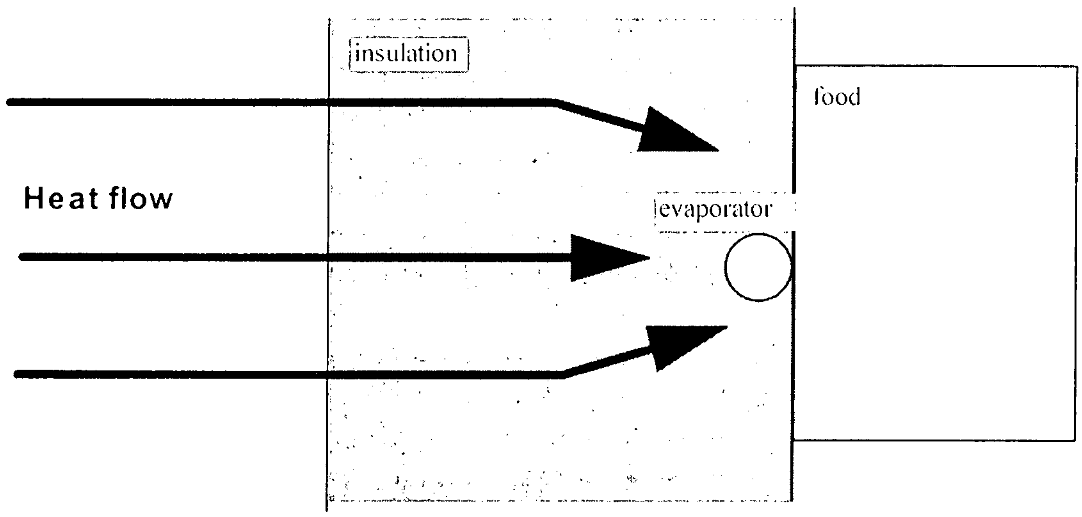


Figure 7 Heat flow through the insulation of a chest freezer.

The heat transfer coefficient U (k) depends on the thickness (x) and thermal conductivity (k) of the freezer insulation (Internal and external surface heat transfer coefficients are relatively small and can be ignored).

$$\frac{1}{U} = \frac{x}{k}$$

Therefore, if the thickness is increased and the thermal conductivity reduced the heat flow will be less and the energy consumption reduced.

Increase the evaporator surface area

The evaporator must be large enough (the surface area big enough) to evaporate all the refrigerant entering the evaporator. If the surface area is reduced then a larger temperature difference is required to transfer the heat from the insulation. In addition, the temperature of the wall of the freezer will increase as the gap between each coil of the evaporator increases. Therefore, as the evaporator is increased in length the coils are closer together and a smaller temperature difference is needed to evaporate the refrigerant. However, the pressure drop through the evaporator will increase and the saturated temperature will reduce as the refrigerant flows through the evaporator. The suction pressure at the compressor will therefore reduce, increasing the energy consumption. To counter this a larger diameter evaporator may be needed.

Increase the height of the evaporator over the load line (Chest freezer)

The warmest point in a chest freezer is in the centre at the top of the food. Heat is radiated from the lid of the freezer to the food. In order to remove this heat and keep the temperature of the food colder than -18°C the air over the food must be colder than -18°C. This cold air must flow from the sidewalls of the freezer, rising up as it is heated and flowing back to the freezer under the lid (Figure 8).

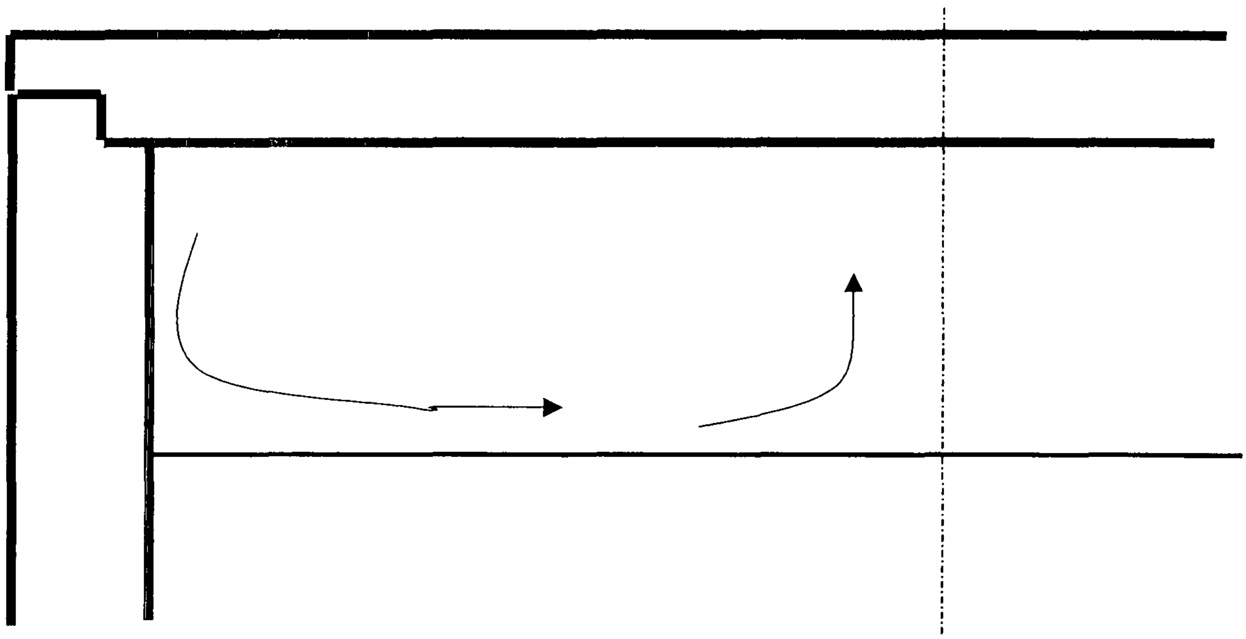


Figure 8 Section through the top of a chest freezer showing how the centre of the cabinet is cooled.

The driving force for the air circulation is the pressure difference between the column of air at the cold sidewall and that in the centre. For maximum air circulation, and hence minimum temperature difference between the side and the centre we require the height of the column to be maximal. Unfortunately, if the height is increased the load line is reduced (The maximum height to which food can be loaded and still be kept at less than -18°C). In any case, to have the sidewall at the coldest possible temperature is an advantage to both increase the load line and reduce the temperature of the centre food pack.

The higher up the wall the evaporator is the warmer the evaporating temperature can be and hence the lower the energy consumption.

In a freezer that is already built and in which the geometry is fixed, if the temperature of the centre food pack is warmer than -18°C then either the load line must be reduced or the evaporating temperature must be reduced, or both.

A possible disadvantage of this is that the temperature of the joint between the cabinet and the lid will be colder, increasing the heat flow into the freezer and increasing the risk of ice formation.

How to increase the evaporator temperature

Figure 9 shows the flow characteristics of a longer and a shorter capillary tube and of a bigger and a smaller compressor. Assuming that the amount of refrigerant in the system and the size of the evaporator are optimal then the system will balance at the intersection of the two characteristics. If the longer capillary tube is used with the bigger compressor then the system will balance with an evaporating temperature at A and if the shorter tube is used with the smaller compressor the evaporator temperature will be B. Thus, the evaporator temperature will be increased and the energy consumption reduced.

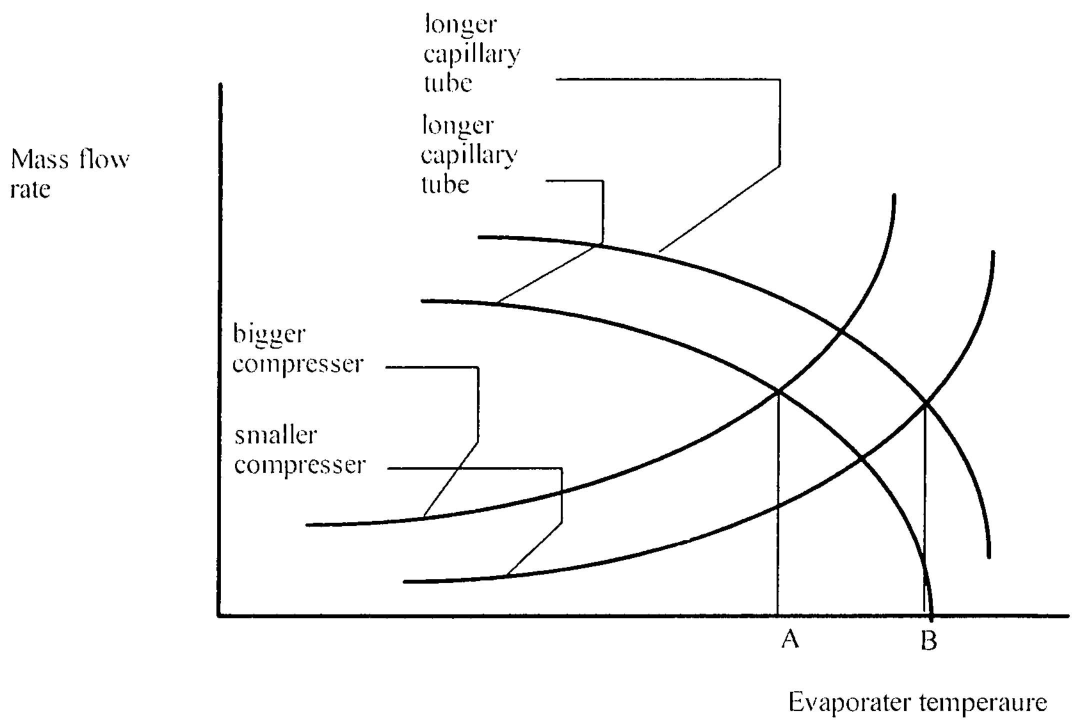


Figure 9 Diagram showing the flow characteristics of 2 capillary tubes and 2 compressors.

The safety of domestic refrigerators and freezers with flammable refrigerants.

Relevant standards used for the assessment

EN 60335-2-24:2001 supersedes **EN 60335-2-24:1994** and Amendments A51 1995, A52 1997, and A53 1997. It is the relevant standard regarding the safety of domestic refrigerators and freezers in the European Union. It is based on IEC 60335-2-24:2000. Only these sections which specifically deal with refrigerators with flammable refrigerants are covered in this document. These notes do not cover the other safety and constructional requirements of refrigerators or of those manufactured with non-flammable refrigerants.

EN 60335-2-24:2001 is based on IEC 60335-2-24:2000 Specification of household and similar appliances. Part 2. Particular requirements. Section 2.24 Refrigerators, food freezers ice cream appliances and ice makers.

The objectives of the standard

This standard seeks to:

1. Prevent any build up of flammable gas to more than 75% of the lower explosive limit (LEL) in or near any electrical components in the event of a leak and
2. Prevent any spark or temperature in excess of the ignition temperature of an explosive concentration of refrigerant from occurring.

There are therefore 2 approaches. One with a protected circuit in which if a leak of flammable gas occurs the concentration cannot accumulate to build up a concentration greater than the lower explosive limit and a second, unprotected circuit, in which if a leak occurs the gas can build up to a concentration greater than the lower explosive limit but there is no source of ignition.
A protected circuit is one that if a leak occurs from it then the leaking refrigerant cannot accumulate in the food compartment or accumulate in any area around the refrigerator. If a protected circuit is identified by an inspection then a leak test must be carried out to show that the protection effectively prevents an explosive mixture from forming within the food compartment. A common type of protected cooling circuit is one that is placed against the inner liner of the refrigerator, outside of the food compartment. If the evaporator is contained inside the cooling compartment then protection is still possible.

Inside a food compartment the concept of a **protected cooling circuit** is defined (22.107, NOTE 2) as appliances in which:

- No part of the cooling system is inside a food storage compartment
- Where any part of the cooling system which is located inside a food storage compartment is constructed so that the refrigerant is contained within an enclosure with at least two layers of metallic material separating the refrigerant from the food storage compartment. Each layer shall have a thickness of at least 0.1 mm. The enclosure has no joints other than the bonded seams of the evaporator where the bonded seam has a width of at least 6 mm.
- Where any part of the cooling system, which is located inside a food storage compartment, has the refrigerant contained in an enclosure, which itself is contained within a separate protective enclosure. If leakage from the containing enclosure occurs, the leaked refrigerant is contained within the protective enclosure and the appliance will not function as in normal use. The protective enclosure shall also withstand the test pressure described in section.

Separate compartments with a common air circuit (through a common evaporator for example) are considered to be a single compartment.

If a protected compartment is identified then the electrical apparatus in this compartment do not have to conform to special regulation for flammable refrigerants.

If the compartment does not comply with the definition of a protected circuit then the electrical components must be of spark proof or better protection.

In addition, all compression type appliances which use flammable refrigerant must be tested to see if, in the event of a leak, an explosive mixture can form around the electrical components outside the food storage compartment. If an explosive mixture can form in these positions then, again the electrics must be spark proof or better. Otherwise, no special protection is required.

Appliances with flammable refrigerants must be subjected to a higher than normal pressure test in order to be sure that in the event of excessive temperature the refrigeration circuit will not rupture or leak. It also serves to test if in the event of an internal explosion damage will not result outside the refrigeration circuit. If a protected cooling system is identified then all accessible surfaces of the protected cooling system shall be scratched in a standard way and then the pressure test repeated in order to ensure the mechanical integrity of the protected system.

Definitions and procedures taken from the Standard

1.1 Scope

It deals with safety rules for such appliances including those that use flammable refrigerants with a maximum mass of the refrigerant of 150g.

2.109 Definition of flammable refrigerant.

This standard refers to refrigerants with a flammability classification of class two or class three, according to ISO5149.

4.7 Test Temperatures

All the tests in this document are to be carried out at an ambient temperature of 20±0.5°C

4.10 Position in room

For the tests of 22.107, 22.108 and 22.109 detailed in EN 60335-2-24:2001, the appliance is empty and installed in the test room as follows:
Appliances other than built-in appliances are placed in a test enclosure, the walls enclosing the appliance as near to all its sides and above as possible, unless the manufacturer indicates in the instructions for installation that a free distance shall be observed from the walls or the ceiling, in which case this distance is observed during the test.

7.2 Marking and instructions

This section refers to information to be marked on the appliance, normally on an ID plate.

The standard states that the appliance shall be marked with:

The power input, in watts, of heating elements and any auxiliary components if greater than 100 watts;
The defrosting input, in watts, if greater than the input corresponding to the rated power input;
Compression type appliances shall be marked with the rated current in amperes;
The letters SN, N, ST or T indicating the climatic class of the appliance
The rated maximum input of lamps, in watts;
The total mass of the refrigerant;
For a single component refrigerant, such as isobutane, at least one of the following needs to be identified on the ID plate, the chemical name, the chemical formula or the refrigerant number.
For a blended refrigerant at least one of the following needs to be identified on the ID plate: the chemical name and nominal proportion of each of the components, the chemical formula and nominal proportion of each of the components, the refrigerant number and the nominal proportion of each of the components, the refrigerant number of the refrigerant blend.

The chemical name or refrigerant number of the principal component of the insulation blowing gas.

Refrigerators with flammable refrigerants should also be marked with a triangle, the perpendicular height of which is at least 15 mm, containing this warning "Caution, risk of fire" shall be placed on the appliance, conforming to the ISO 3864 Symbol B.3.2. This sign should be visible when gaining access to the motor compressor (7.15).

An instruction sheet needs to be included with the appliance. This will include information for handling, installation, cleaning, servicing, replacing illumination lamps and disposal and carry the following warnings,
"WARNING - Keep ventilation openings in the appliance enclosure or in the built-in structure clear of obstruction",

"WARNING - do not use mechanical devices or other means to accelerate the defrosting process, other than those recommended by the manufacturer".
"WARNING - do not damage the refrigerant circuit" (only used when the refrigeration circuit is accessible to the user).
"WARNING - do not use electrical appliances inside the food storage compartment of the appliance unless they are of the type recommended by the manufacturer".

For appliances which use flammable insulation blown gases the instructions sheet shall include information regarding disposal of the appliance.

.

8.1 Protection against live parts

Lamps are not removed before applying the standard test finger, for portable electrical equipment.

22.7 Pressure test

This test refers to practical pressure testing of the refrigerant system. For compression type appliances, including protective enclosures of a protected cooling system using flammable refrigerants, shall withstand a pressure of 3.5 times the saturated vapour pressure of the refrigerant at 70°C for parts exposed to the high side pressure during normal operation, or a pressure of 5 times the saturated vapour pressure of the refrigerant at 20°C for parts exposed only to low side pressure during normal operation. It is specified that all pressures are gauge pressures. Therefore the test pressure for an isobutane system is 35.1 bar gauge for the high-pressure side and 10.2 bar gauge for the low-pressure side.
The appropriate part of the appliance under test is subjected to a pressure that is gradually increased hydraulically until the required test pressure is reached. The pressure is maintained for 1 minute. The part under test shall show no leakage.

The test is not carried out on motor compressors complying with IEC 335-2-34. *Specification for safety of household and similar electrical appliances. Particular requirements. Motor compressors.* This standard deals with the safety of hermetic and semi-hermetic compressors.

22.107 Simulated leakage tests for compression type appliances with a protected cooling system.

Compression-type appliances with a protected cooling system, and which use flammable refrigerants, shall be constructed to avoid any fire or explosion hazard, in the event of leakage of the refrigerant from the cooling system. Compliance is checked by the following 2 tests.

22.107.1 Simulated leakage tests

This test simulates a leakage at the most critical points of the cooling system. Critical points are interconnecting joints between parts of the refrigerant circuit including the gasket of a semi-hermetic motor compressor. Welded telescopic joints of the motor-compressor housing, the welding of the pipes through the motor-compressor housing and the welding of the fusite not considered to be pipework joints and need not be tested. To find the most critical point of the cooing system it may be necessary to carry out more than one test.

The method for simulating a leakage at the most critical point is to inject refrigerant vapour through a capillary tube at a critical point. The capillary tube, which may need to be positioned before foaming the appliance, shall have a diameter of 0.7 mm ± 0.05 mm and a length of between 2 and 3 metres. During this test the appliance is tested with doors and lids closed and is switched off, or operated, whichever gives the more unfavourable result. During the test, in which the appliance is operated, gas injection is started at the same time as the appliance is first switched on.
The quantity of refrigerant of the type indicated by the manufacturer to be injected is equal to 80% of the nominal charge of the refrigerant ±1.5 grams, or the maximum which can be injected in one hour, whichever is the smaller. The quantity injected is taken from the vapour side of a gas bottle that shall contain enough liquid refrigerant to ensure that at the end of the test there is still liquid refrigerant left in the bottle.
The gas bottle is kept at a temperature of 32±1°C for leakage simulation on low-pressure circuits and 70±1°C for leakage simulation on high-pressure circuits.
A simple way of compiling with the above is to fill a small refrigerant bottle with ±1.5g of 80% of the charge and connect this to the capillary tube with a valve. The gas bottle is kept in a bath of water at the required temperature to maintain the vapour pressure of the refrigerant in the bottle. The valve is opened at the start of the test and closed one hour later.
The concentration of leaked refrigerant inside the food storage compartments and inside any internal or external electrical component compartments, except those which contain only non-self-resetting protective devices necessary for complying with clause 19, is measured continuously from the beginning of the test and for at least 1 hour after the injection of the gas has stopped, a maximum of 2 hours after the start of the test.
The instrument used for monitoring gas concentration, such as those that use infrared sensing techniques, should have a fast response, typically 2 to 3s and not unduly influence the result of the test. If gas chromatography is to be used, the gas sampling in confined areas should occur at a rate not exceeding 2ml every 30s. Any type of measuring instrument may be used provided that it does not unduly influence the results.
The measured value shall not exceed 75% of the lower explosive limit of the refrigerant, (1.8% by volume for isobutane), and not exceed 50% of the lower explosive limit of the refrigerant for a period exceeding 5 minutes. If the appliance meets these requirements there are no additional requirements applicable for the electrical components located inside food storage compartments. If the concentration increases above these limits the appliance shall be considered as having an **unprotected cooling system** and should be assessed as an unprotected cooling system, complying with 22.108.

22.107.2 Mechanical integrity of a protected cooling system.

All accessible surfaces of protected cooling system components, including accessible surfaces in intimate contact with the protected cooling systems, are scratched using the tip of a special tool. The details of the scratching tool tip are given in Annexe 1 of the standard. The tool is drawn across the surface to be tested at a rate of approximately 1 mm per second. The force at right angles to the surface to be tested is 35±3 N and the force parallel to the surface to be tested shall not exceed 250N. The surface to be tested is scratched at 3 different positions in a direction at right angles to the axis of the channel and at 3 different positions on the channel, in a direction parallel to it. In the latter case the length of the scratch shall be approximately 50mm. The scratches must not cross each other. The standard dictates that the appropriate part of the appliance shall withstand the test of 22.7, the test pressure being reduced by 50%. For an isobutane system the test pressure will be 17.55 bar gauge for the high-pressure side and 5.04 bar gauge for the low-pressure side.

22.108 Unprotected cooling systems

Appliances with unprotected cooling systems must use electrical apparatus, such and switches and thermostats, that conform to Section 3, Clauses 16 and 17, and Section 4 of IEC 60079-15 in food storage compartments..

22.108 Simulated leakage test for compression-type appliances with unprotected cooling systems.

This test determines that if refrigerant leaks from the unprotected cooling circuit the concentration does not reach 75% of the LEL in close proximity to any electrical apparatus on the outside of the appliance, so as to cause an explosion.

Refrigerant leakage into food storage compartments shall not result in an explosive atmosphere outside the food storage compartment in areas where electrical apparatus are mounted, except those which contain only non-self resetting protective devices necessary for complying with clause 19, when doors or lids remain closed or when opening or closing doors or lids unless these apparatus have been tested and found to comply with those suitable for use in an explosive atmosphere.

The test is performed in a draught-free location with the appliance switched off or operated, whichever gives the more unfavourable result. During a test in which the appliance is operated, gas injection is started at the same time as the appliance is first switched on.

The test is carried out twice and is repeated a third time if one of the first two tests gives more than 40% of the lower explosive limit.

Through an appropriate orifice 80% of the nominal refrigerant charge ±1.5 g, in the vapour state, is injected into a food storage compartment in a time not exceeding 10 min and the orifice is then closed. The injection shall be as close as possible to the centre of the back wall of the compartment at a distance from the top of the compartment approximately equal to one third of the height of the compartment. Thirty minutes after the injection is completed, the door and lid is opened at a uniform rate in a time between 2 and 4s, to an angle of 90° or to the maximum possible, whichever is less. For appliances with more than one door or lid the most unfavourable sequence or combination for opening the lids or doors is used. For appliances fitted with fan motors the test is done with the most unfavourable combination of motor operation.

The concentration of leaked refrigerant is measured continuously as close as possible to the electrical apparatus, other than non-self resetting apparatus, from the beginning of the test. The concentration values are recorded until they decrease.

The measured value shall not exceed 75% of the LEL of the refrigerant as specified in Table 101 of EN 60335-2-24:2001 (1.8%v/v for R600a) and shall not exceed 50% of the LEL of the refrigerant for a period exceeding 5 min.

The test is repeated except that the door or lid is subjected to an open/close sequence at a uniform rate in a time of between 2 and 4s, the door or lid being opened to an angle of 90° or to the maximum possible, whichever is less, and closed during the sequence.

22.109 Simulated leak from external joints

This clause refers to compression type appliances which use flammable type refrigerants. They shall be constructed so that leaked refrigerant will not stagnate so as to cause a fire or explosion hazard in areas outside the food storage compartments where the appliance electrical components, other than non-self resetting protective devices necessary for complying with clause 19, are fitted.

Separate components such as thermostats which contain less than 0.5 g of flammable gas are not considered to cause a fire or explosion hazard in the event of a leakage of the component itself.

If the electrical apparatus under consideration does not comply with at least Type N protection (Section 3, Clauses 16 and 17, and Section 4 of IEC 60079-15 (formally IEC 79-15) for Group IIA gases, or with other types of protection for electrical apparatus for potentially explosive atmospheres covered by the IEC 79 series) then the following test is carried out. Electrical apparatus is defined as electrical and electronic components, related circuits and associated constructions.

The test is performed in a draught-free location with the appliance switched off or operated, whichever gives the more unfavourable result. If the appliance is operated gas injection is started at the same time as the appliance is first switched on.

A quantity of 50% of the refrigerant charge ±1.5 g is injected into the considered area. Injection is to be at a constant rate over a period of one hour and is to be at the point of closest approach of pipe-work joints in external parts of the cooling circuit to the electrical apparatus under consideration. Any direct injection shall be avoided. The concentration of leaked refrigerant is measured continuously as close as possible to the electrical apparatus from the beginning of the test until it starts to decrease.

The measured value shall not exceed 75% of the LEL of the refrigerant and shall not exceed 50% of the LEL of the refrigerant for a period exceeding 5 minutes. The LEL for R600a (Isobutane) is given as 1.8% v/v.

During a test in which the appliance is operated, gas injection is started at the same time as the appliance is first switched on.

22.110 Surface temperatures

Temperatures on surfaces that may be exposed to leakage of flammable refrigerants shall not exceed the ignition temperature of the refrigerant, reduced by 100K. The ignition temperature of R600a (Isobutane) is specified as 494°C in EN 60335-24-2:2001, therefore surface temperatures must be cooler than 394°C.

Test	State	Position	Temperature °C	Operation	Air movement	Amount	Conditions	Assessment	Details	Paragraph No in Standard
Pressure	Empty	Anywhere	20±5 °C	off	any	n/a		No sign of leakage		22.7
Scratch test	Empty	Anywhere	20±5 °C	off	any	n/a		No sign of leakage	Scratch 3 across and 3 along, 50 mm long protected circuits	22.107.2
Leak test (protected)	Empty, doors closed	Test enclosure	20±5 °C	on and off	any	80% of charge or amount in 1 hour		see note 1	CAP 0.7mm dia, 2-3m long	22.107.1
Leak test (unprotected)	Empty. Open door 30min after refrigerant injection is complete	Test enclosure	20±5 °C	on and off	draft free	80% charge in 10 min	30min after injection complete open door	see note 1	CAP 0.7mm dia, 2-3m long	22.108
Leak from compressor / condenser	Empty	test enclosure	20±5 °C	on and off	draft free	50% charge steady over 1 hour		see note 1	CAP 0.7mm dia, 21m long?	22.109

Note 1 75% of LEL, >50%LEL allowed for <5min.

Conversion of a Little Swan BC 47 Refrigerator from R12 to R600a

Energy Consumption Test

FOOD REFRIGERATION AND PROCESS ENGINEERING RESEARCH CENTRE

Food Refrigeration and Process Engineering Research Centre (FRPERC)

Churchill Building
Langford
Bristol
BS40 5DU UK

Tel +44 (0)117 928 9239
Fax +44 (0)117 928 9314
e-mail frperc-bristol@bristol.ac.uk

Summary

The energy consumption of the converted R600a refrigerator was 0.381 kWh/24h and that of the R12 refrigerator 0.382 kWh/24h. The converted freezer used 0.4 % less energy than the original R12 freezer.

General Introduction

Domestic refrigerator manufacturers have for the past 50 years, been using R12 as the refrigerant. In Little Swan, this refrigerant is now being phased out, as it is environmentally harmful. R600a has been identified as the replacement. This study was to redesign one of Little Swan's refrigerators, a BC 47, to convert it from R12 to R600a. The brief was that its performance should be the same or better than the R12 model and as few changes as possible were to be made. It was expected that only the compressor, capillary tube and the charge would need to be changed. Some alterations may need to be made to the electrical switches and lights to comply with hydrocarbon safety regulations.

Introduction to Energy Consumption Test

Previous reports have covered the optimisation of the size of the capillary tube and charge in the R600a version of the BC 47 refrigerator (1). The aim of the tests described in this report was to measure the energy consumption of the R12 and converted R600a refrigerators according to the method described in ISO 7371 (The Standard).

Method

The two refrigerators previously tested (Type BC 47, one with R12 and one with R600a) were used, with the compressor changed and the capillary tube and charge optimised in the R600a refrigerator (Table 1).

	R12	R600a
Compressor:		
Manufacturer	East Tech Electric Co.	Dong Bei
Type	QD30L	QDHC51
Displacement cc	3.0	5.1
ASHRAE Capacity at -23.3°C W	70	68
Input power at -23.3 °C W	87	80
Voltage/Frequency	220V/50Hz.	220V/50Hz.
Capillary tube:		
Length m	1.9	1.9
Inside diameter mm	0.68	0.68
N2 flow rate l/min		As R12
Charge g	50	19.6

Table 1 Refrigeration system information for the refrigerators under test.

The ambient temperature in the test room was 25±0.5°C as required in the Standard (classes N and ST). The temperature gradient between the floor and the ceiling was less than 2°C/m.

The refrigerators were run until the temperatures were stable. If the average temperature of the three points measured within the refrigerator was not 5°C (or close to 5°C) the thermostat was adjusted and the temperatures allowed to stabilise again. After the temperatures had been stable for 24h the test was started and continued for at least 24 h. If the average temperature within the refrigerator was not 5°C the thermostat was adjusted as described in The Standard and the test repeated. The total energy consumption at 5°C was found by interpolating the results of the two tests (one no more than 2°C warmer than 5°C and the other no more than 2°C cooler), as described in the Standard. No measured temperature within the refrigerator exceeded 10°C or fell below 0°C during any of the tests.

Instrumentation

Temperatures were measured at the same positions and in the same way as used in the previous tests. Electrical energy to each refrigerator was measured with a Northern Design PEA200 energy meter, fitted with a 2 Amp current transformer, measuring the true power, current, voltage and energy consumed over the test period (accuracy ±1%).

Results

The average temperature of the storage compartment, the thermostat setting and the energy consumption for each refrigerator is shown in Table 2. R600a values are taken from the interpolated results.

Refrigerant	R12	R600a
Thermostat setting	~1	~1
Average fridge temperature (°C)	5.0	5.0
Compressor run time %	13.1	16.7
Energy Consumption kWh/24h	0.3825	0.3810

Table 2 The average refrigerator temperature, the thermostat setting and the energy consumption for the R12 and the R600a refrigerators.

The warmest of the three temperatures measured in the fresh food storage compartment was the one nearest the bottom.

The R600a compressor ran for 16.7 % of the time and the energy consumption was 0.3810 kWh/24h. The R12 compressor ran for 13.1 % of the time and the energy consumption was 0.3825 kWh/24h. The converted R600a refrigerator used 0.4 % less energy than the R12 refrigerator.

Conclusions

The energy consumption of the converted R600a refrigerator was 0.4 % less than that of the R12 refrigerator when measured according to ISO 7371.

The energy consumption of the R600a refrigerator was 0.3810 kWh/24h.

References

(1) Conversion of a Little Swan BC 47 refrigerator from R12 to R600a. Pull down and continuos running tests, capillary tube and refrigerant charge optimisation. FRPERC University of Bristol. June 2002.

(2) Conversion of a Little Swan BC 47 refrigerator from R12 to R600a. Storage tests at 16 and 32°C. FRPERC University of Bristol. June 2002.

Conversion of a Little Swan BC47 Refrigerator from R12 to R600a

Pull-down and continuous running tests

Capillary tube and refrigerant charge optimisation

FOOD REFRIGERATION AND PROCESS ENGINEERING RESEARCH CENTRE

Food Refrigeration and Process Engineering Research Centre (FR&PERC)

Churchill Building
Langford
Bristol
BS40 5DU UK
Tel +44 (0)117 928 9239
Fax +44 (0)117 928 9314
e-mail frperc-bristol@bristol.ac.uk

Summary

A BC47 refrigerator was fitted with an R600a Dong Bei QDHC51 compressor and the condenser was extended by 2.6m using 6mm diameter copper tube. The second BC47 refrigerator operated unaltered with R12. The optimum charge for the BC47 refrigerator, when converted to operate on R600a, was 19.6g of refrigerant with a capillary tube length of 1.9m and a diameter of 0.68mm. This gives a similar thermal performance to the R12 refrigerator.

Introduction

Domestic refrigerator manufacturers have for the past 50 years been using R12 as the refrigerant. In Little Swan this refrigerant is now being phased out, as it is environmentally harmful. R600a has been identified as the replacement.
This study was to redesign one of Little Swan's refrigerators, to convert it from R12 to R600a. The brief was that its performance should be the same or better than the R12 model and as few changes as possible were to be made. It was expected that only the compressor, the capillary tube and the charge would need to be altered. Some alterations may be required to electrical components in order to comply with hydrocarbon safety regulations.

Method

Two refrigerators, type BC47 were used. One refrigerator was fitted with an R600a compressor and the other was unaltered with the original R12 compressor (Table 1). With the condenser unaltered the condensing temperature was excessive, both in the original R12 refrigerator and the converted one. The condenser of the R600a refrigerator was therefore extended by 2.6m using 6mm diameter copper tube to reduce the condensing temperature. The charge was adjusted to optimise performance.
In all tests the thermostat was removed to ensure continuous operation of the compressor.

	R12	R600a
Compressor:		
Manufacturer	East Tech Electric Co.	Dong Bei
Type	QD30L	QDHC51
Displacement cc	3.0	5.1
ASHRAE Capacity at -23.3°C W	70	68
Input power at -23.3 °C W	87	80
Voltage/Frequency	220V / 50Hz	220V / 50Hz
Capillary tube:		
Length m	1.9	1.9
Inside diameter mm	0.68	0.68
N2 flow rate l/m*		As R12 refrigerator

Table 1. System information * Values measured on test refrigerators.

The converted R600a refrigerator and the untouched R12 refrigerator were tested in accordance with ISO standard 7371. Both refrigerators were placed in an insulated, temperature controlled room on a test platform.

The room was controlled to an ambient temperature of 32°C, the warmest temperature for climate class N. Constant airflow was achieved by setting fans in the room to maintain the specified air velocity and temperature gradients.

The test platform was 0.3m above the floor and had three sides, which extended 0.3m above the top of the refrigerator. The sidepieces extended 0.3m out from the back piece and 0.3m from the refrigerator sides. The refrigerator was placed on the platform with its back as close as possible to the wall. The compressor was touching the rear surface of the platform and the distance between the rear condenser and the surface was 40mm (Figure 1). The whole platform was painted dull black.

Initially the refrigerator was in approximate thermal equilibrium with the test room. It was then started and run continuously until the measured temperatures were steady. These values were then recorded. The charge was then altered and a similar pull-down test conducted until an optimum value for charge was obtained.

Instrumentation

The refrigerators had T-type thermocouples placed around the refrigeration circuit as shown in Figure 2. The thermocouples were held in contact with the pipes by tape and insulated with 25mm of closed cell insulation. Where the refrigerator insulation had been cut away to gain access to the evaporator, the walls were refilled with expanded polyurethane foam. A thermocouple was positioned at the geometric centre of the refrigerator. This gave a representative temperature inside the refrigerator.

Electrical power to the compressor was measured with a Northern Design PEA200, fitted with a 2 Amp current transformer, measuring the true power, current and voltage. The energy consumption was measured over the test period.

A Datascan module connected to a PC running Labtech software was used to record the results.

Results

Data from optimisation tests

Refrigerator	R12	R600a	R600a
Date		2-5-02	3-5-02
Charge	50g	32g	19.6g
Length of capillary	1.9m 0.68 dia	1.9m 0.68 dia	1.9m 0.68 dia
Evaporator start	-30.3	-11.3	-26.7
Evaporator end	-30.6	-10.5	-26.0
Accumulator end	-30.3	-10.0	-25.7
Suction line	26.0	-6.8	14.3
Discharge line	81.9	64.9	74.2
Condenser	44.0	60.1	43.9
Filter entry	44.5	54.9	42.7
Filter exit	44.4	55.4	42.8
Superheat	-0.3	0.8	0.7
Sub-cooling	-0.5	5.2	1.2

The test on 2-5-02 suggested a significant overcharge of the refrigeration circuit; resulting in a very high condensing pressure, a large amount of sub-cooling at the end of the condenser and a warm evaporator.

The charge was reduced to 19.6g. Temperatures recorded on 3-5-02 suggest the charge and capillary tube were optimised for the system, temperatures on the converted unit being comparable to those of the original R12 model.

DISCUSSION

The thermostat fitted to the converted R600a refrigerator should be of class N, non-sparking, unless the box into which they are sealed could be proved to be adequate to prevent any R600a refrigerant that may leak from the refrigeration circuit, from entering. See the document "The safety of domestic refrigerators and freezers with flammable refrigerants" for details.

The easiest changes to recognise in the temperatures measured were the superheat at the evaporator exit, and the sub-cooling at the exit of the condenser. Optimum performance would occur when there is between 1 and 2°C sub-cooling and 0°C superheat.

Conclusions

The chosen compressor was the Dong Bei QDHC51. With this compressor, the optimum charge is 19.6g of R600a. The optimum capillary tube for this system had a length of 1.9m and an internal diameter 0.68mm. The condenser was extended by 2.6m using 6mm diameter pipe.

Figures

Figure.1 Positioning of refrigerator on test platform.

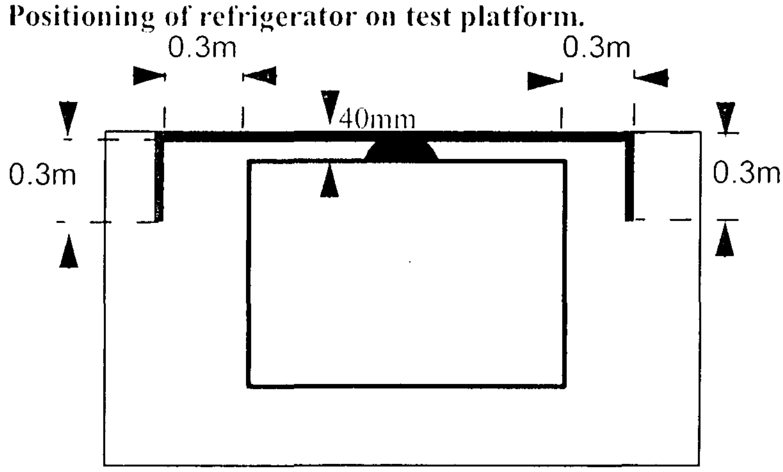
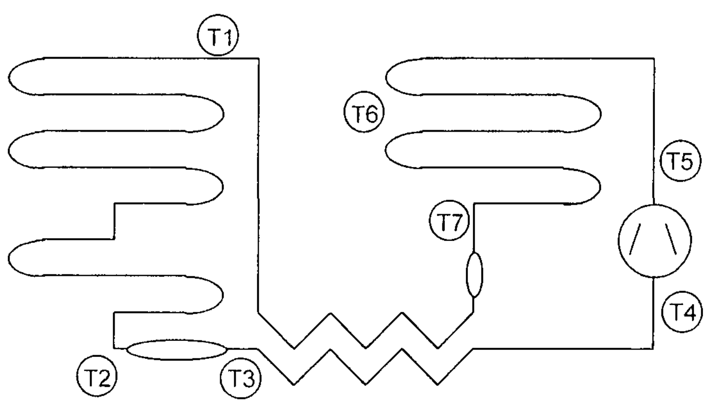


Figure.2 Positioning of thermocouples on system.



Key

T1 Evaporator start
T2 Evaporator end
T3 Accumulator end
T4 Suction line
T5 Discharge line
T6 Condenser
T7 Filter entry

Conversion of a Little Swan BC47 Refrigerator from R12 to R600a

Specification of converted Refrigerator

FOOD REFRIGERATION
AND PROCESS
ENGINEERING
RESEARCH
CENTRE

Food Refrigeration and Process Engineering Research Centre (FRPERC)

Churchill Building
Langford
Bristol
BS40 5DU UK

Tel +44 (0)117 928 9239
Fax +44 (0)117 928 9314
e-mail frperc-bristol@bristol.ac.uk

General Introduction

Domestic refrigerator manufacturers have for the past 50 years, been using R12 as the refrigerant. In Little Swan, this refrigerant is now being phased out as it is environmentally harmful. R600a has been identified as the replacement. This study was to redesign one of Little Swan's refrigerators, a BC47, to convert it from R12 to R600a. The brief was that its performance should be the same or better than the R12 model and as few changes as possible were to be made. It was expected that only the compressor, capillary tube and the amount of charge would need to be changed. Some alterations may need to be made to the electrical switches and lights to comply with hydrocarbon safety regulations.

Introduction to this specification

This report gives the specification for the components of the BC 47 refrigerator that need to be changed to convert it from R12 to R600a.

Specification of altered components

Compressor:	R12	R600a
Manufacturer	East Tech Electric Co.	Dong Bei
Type	QD30L	QDHC51
Displacement (cc)	3.0	5.1
ASHRAE Capacity at -23.3°C (W)	70	68
Input power at -23.3 °C (W)	87	80
Voltage/Frequency	220V/50Hz.	220V/50Hz.

Capillary tube:	R12	R600a
Length m	1.9	1.9
Inside diameter mm	0.68	0.68
N2 flow rate l/m*		As R12

*values measured on test refrigerators

Charge	R12	R600a
Refrigerant charge (g)	50	19.6

Condenser	R12	R600a
Length (m)	~6	~9
Diameter (mm)	5	5

For the optimisation, the condenser was extended by 2.6m using 6mm diameter copper tube. This additional tubing was added as a skin condenser to the back of the fridge using aluminium adhesive tape. The coils drained downhill and were added between the compressor and the original condenser, as in the sketch below. (Figure 1).

In the standard production refrigerator, the coils of the skin condenser are vertical. The efficiency of the refrigerator could be improved by changing the design to that sketched in Figure 1 below.

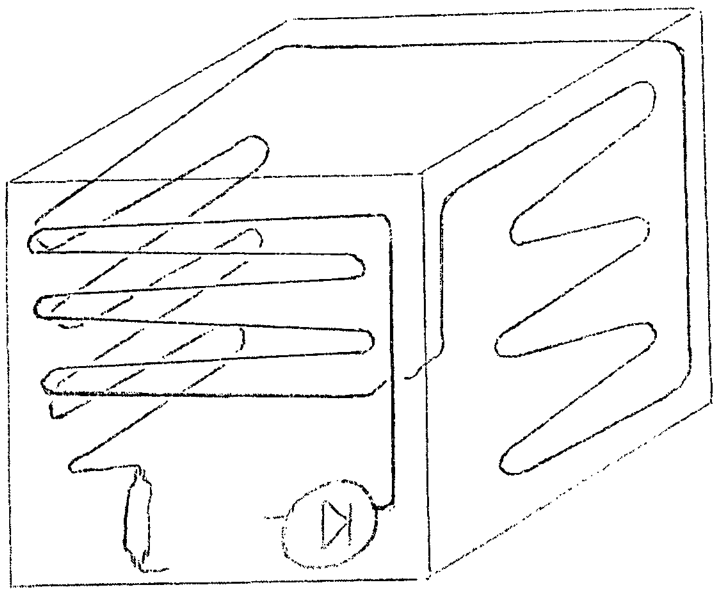


Figure 1. Sketch of proposed condenser. Viewed from rear of refrigerator.

Tests

Pulldown, storage and energy consumption Tests have been carried out (1, 2 & 3).

When the freezers operated in ambient temperatures of 32 and 16°C (climate class N), the fresh food storage temperatures complied with ISO 7371.

The energy consumption of the converted R600a freezer was 0.4 % less than that of the R12 freezer when measured according to ISO 7371. The energy consumption of the R600a freezer was 0.3825 kWh/24h compared to 0.3810 kWh/24h for the R12 freezer.

References

(1) Conversion of a Little Swan BC 47 refrigerator from R12 to R600a - Pulldown and continuos running tests, capillary tube and refrigerant charge optimisation. FRPERC University of Bristol. June 2002.
(2) Conversion of a Little Swan BC 47 refrigerator from R12 to R600a Storage tests at 16 and 32°C. FRPERC University of Bristol. June 2002.
(3) Conversion of a Little Swan BC 47 refrigerator from R12 to R600a Energy consumption test. FRPERC University of Bristol. June 2002.

Conversion of a Little Swan BC 47 Refrigerator from R12 to R600a

Storage Tests at 16 & 32°C

FOOD REFRIGERATION AND PROCESS ENGINEERING RESEARCH CENTRE

Food Refrigeration and Process Engineering Research Centre (FRPERC)

Churchill Building
Langford
Bristol
BS40 5DU UK
Tel: +44 (0)117 928 9239
Fax: +44 (0)117 928 9314
e-mail: frperc-bristol@bristol.ac.uk

Summary

The purpose of these tests was to ensure the storage temperatures of the BC 47 refrigerator complied with the ISO Standard 7371. One freezer was operated with R12 and one with R600a, both in ambient temperatures of 32 and 16°C.

In an ambient temperature of 16°C, the coldest ambient temperature for climate class N, a thermostat setting of 0.5 was used to maintain fresh food storage temperatures in accordance with ISO 7371

In an ambient temperature of 32°C, the warmest ambient temperature for climate class N, a thermostat setting of 3.0 was used to maintain fresh food storage temperatures in accordance with ISO 7371

The converted R600a refrigerator can be classified as suitable for fresh food storage under ISO Standard 7371.

General Introduction

Domestic refrigerator manufacturers have for the past 50 years been using R12 as the refrigerant. In Little Swan this refrigerant is now being phased out, as it is environmentally harmful. R600a has been identified as the replacement. This study was to redesign one of Little Swan's refrigerators, a BC 47, to convert it from R12 to R600a. The brief was that its performance should be the same or better than the R12 model and as few changes as possible were to be made. It was expected that only the compressor, capillary tube and the charge would need to be changed. Some alterations may need to be made to the electrical circuits and lights to comply with hydrocarbon safety regulations.

Introduction to this report

A previous report covers the optimisation of the size of the capillary tube and charge in the R600a version of the BC 47 refrigerator (1). The aim of the test described in this report was to measure the storage temperature of the converted R600a and the original R12 refrigerator at the warmest and coldest ambient temperatures, (32 and 16°C for climate class N), according to the method described in ISO Standard 7371.

Method

The two refrigerators used in the pull down and continuous running tests (1) were used for these tests. Both were the model BC 47. The R600a refrigerator had the compressor, optimum capillary tube and charge reported in the previous tests (Table 1).

	R12	R600a
Compressor:		
Manufacturer	East Tech Electric Co.	Dong Bei
Type	QD30L	QDHC51
Displacement cc	3.0	5.1
ASHRAE Capacity at -23.3°C W	70	68
Input power at -23.3 °C W	87	80
Voltage/Frequency	220V/50Hz.	220V/50Hz.
Capillary tube:		
Length m	1.9	1.9
Inside diameter mm	0.68	0.68
N2 flow rate l/m*		Same as R12
Charge g	50	19.6

Table 1 Refrigeration system information for the freezers under test. *values measured on test refrigerators

Ambient temperature 32°C

The ambient temperature in the test room was 32±0.5°C (climate class N). The temperature gradient between the floor and the ceiling was less than 2°C/m.

The temperature of the chilled storage compartment was measured with thermocouples placed inside brass blocks, (Figure 1), in accordance to the Standard ISO 7371.

For each test the refrigerator was run with a known thermostat setting until the temperatures over repeated cycles were stable as defined in the Standard. Each test continued for a minimum of 24 hours.

Ambient temperature 16°C

The ambient temperature in the test room was 16±0.5°C (climate class N). The temperature gradient between the floor and the ceiling was less than 2°C/m.

The temperature of the chilled storage compartment was measured with thermocouples placed inside brass blocks, (Figure 1), in accordance to the Standard ISO 7371.

For each test the refrigerator was run on a known thermostat setting until the temperatures over repeated cycles were stable as defined in the Standard. Each test continued for a minimum of 24 hours.

Instrumentation

Temperatures were measured at the positions shown in Figure 2 of Reference (1) (Pull down and continuous running tests).

The storage temperatures were measured with thermocouples placed inside brass blocks and were recorded on the data logger with the other temperatures (1).

Results

The temperatures of the brass blocks after stabilisation are shown in Table 2.

	R12		R600a	
Ambient Temp.	16°C	32°C	16°C	32°C
Thermostat Setting	Continuous	Continuous	0.5	3.0
Top average	-7.2	-2.9	3.3	0.9
Middle average	-4.5	1.0	5.2	5.3
Bottom average	-4.5	1.1	5.1	5.3
Mean	-5.4	-0.3	4.5	3.8
Max	-4.0	1.4	5.6	5.5
Min	-8.0	-3.4	2.4	0.4

Table 2 The measured temperatures at each point during the storage tests on the BC 47 refrigerators. Figure 1 shows the location of each position within the refrigerator.

In an ambient of 32°C, the warmest temperature in the R600a refrigerator was 5.5°C, measured 50mm from the bottom of the refrigerator, (Figure 1). The warmest temperature measured was colder than 10°C. The average temperature was less than 5°C. The minimum temperature measured was warmer than 0°C. The refrigerator can therefore be classified as suitable for fresh food storage under the ISO Standard 7371.

In an ambient of 16°C, the warmest temperature in the R600a refrigerator was 5.6°C, measured in the middle of the refrigerator, (Figure 1). The warmest temperature measured was colder than 10°C. The average temperature was less than 5°C. The minimum temperature measured was warmer than 0°C. The refrigerator can therefore be classified as suitable for fresh food storage under the ISO Standard 7371.

Discussion

In each test the warmest temperature measured was colder than 10°C. The average temperature was less than 5°C. The minimum temperature measured was warmer than 0°C. The refrigerator can therefore be classified as suitable for fresh food storage under the ISO Standard 7371.

Conclusions

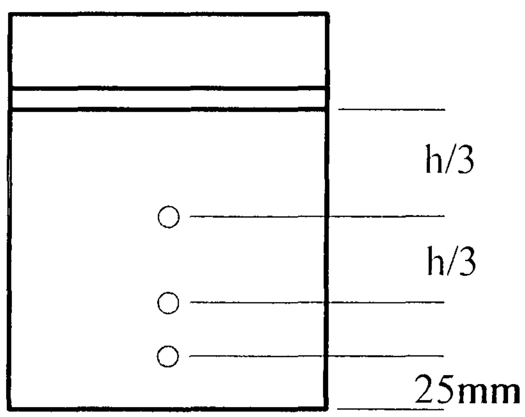
When the refrigerators operated in ambient temperatures of 32 and 16°C the performance fulfilled the ISO Standard requirements of fresh food storage cabinet.

The temperatures measured within the storage compartment of the converted refrigerator were within the limits stated in the Standard without running the refrigerator continuously. The refrigerator can therefore be classified as suitable for fresh food storage.

References

(1) Conversion of a Little Swan BC 47 refrigerator from R12 to R600a. Pull down and continuous running tests, capillary tube and refrigerant charge optimisation. FRPERC University of Bristol. June 2002.

Figure 1



View from front

Brass blocks all in vertical line up the centre of the cabinet

Diagram of the BC 47 refrigerator showing the position of the brass blocks during the storage temperature tests.

Conversion of a Little Swan BCD 218 Fridge-Freezer from R12 to R600a

Energy Consumption Test

FOOD REFRIGERATION
AND PROCESS
ENGINEERING
RESEARCH
CENTRE

Food Refrigeration and Process Engineering Research Centre (FRPERC)

Churchill Building
Langford
Bristol
BS40 5DU UK

Tel +44 (0)117 928 9239
Fax +44 (0)117 928 9314
e-mail frperc-bristol@bristol.ac.uk

Summary

The energy consumption of the converted R600a freezer was 0.9482 kWh/24h and that of the R12 freezer was 1.036 kWh/24h. The converted freezer used 8.5 % less energy than the original R12 freezer.

General Introduction

Domestic freezer manufacturers have for the past 50 years, been using R12 as the refrigerant. In Little Swan, this refrigerant is now being phased out, as it is environmentally harmful. R600a has been identified as the replacement. This study was to redesign one of Little Swan's freezers, a BCD 218, to convert it from R12 to R600a. The brief was that its performance should be the same or better than the R12 model and as few changes as possible were to be made. It was expected that only the compressor, capillary tube and the charge would need to be changed. Some alterations may need to be made to the electrical switches and lights to comply with hydrocarbon safety regulations.

Introduction to Energy Consumption Test

Previous reports have covered the optimisation of the size of the capillary tube and charge in the R600a version of the BCD 218 freezer (1). The aim of the tests described in this report was to measure the energy consumption of the R12 and converted R600a freezers according to the method described in ISO 8187 (The Standard).

Method

The two freezers previously tested (Type BCD 218, one with R12 and one with R600a) were used, with the compressor changed and the capillary tube and charge optimised in the R600a freezer (Table 1).

	R12	R600a
Compressor:		
Manufacturer	National	Dong Bei
Type	D66L15RAX5	QD88YG
Displacement cc	6.6	8.8
ASHRAE Capacity at -23.3°C W	180	160
Input power at -23.3 °C W	136	101
Voltage/Frequency	220V/50Hz.	220V/50Hz.
Capillary tube:		
Length m	2.5	3.95
Inside diameter mm	0.68	0.8
N2 flow rate l/min		7.65
Charge g	170	62

Table 1 Refrigeration system information for the freezers under test.

The ambient temperature in the test room was 25±0.5°C as required in the Standard (classes N and ST). The temperature gradient between the floor and the ceiling was less than 2°C/m. The freezers were loaded as for the storage temperature tests, according to the Standard (see Figure 1 in the storage temperature test report 2).

The freezers were run until the temperatures were stable. If the temperature of the warmest M-pack was not -18°C (or close to -18°C) and / or the average temperature of the three points measured within the fridge was not 5°C (or close to 5°C), the thermostat was adjusted and the temperatures allowed to stabilise again. After the temperatures had been stable for 24h the test was started and continued for at least 24 h. If the temperature of the warmest M-pack was not exactly -18°C and / or the average temperature of the fridge was not exactly 5°C, the thermostat was adjusted as described in The Standard and the test repeated. The total energy consumption for the warmest M-pack at -18°C and the average fridge temperature at 5°C was then found by interpolating the results of the two tests (one no more than 2°C warmer than -18°C and the other no more than 2°C cooler), as described in the Standard. No measured temperature within the fridge exceeded 10°C or fell below 0°C during any of the tests.

Instrumentation

Temperatures were measured at the same positions and in the same way as used in the previous tests. Electrical energy to each freezer was measured with a Northern Design PEA200 energy meter, fitted with a 2 Amp current transformer, measuring the true power, current, voltage and energy consumed over the test period (accuracy ±1%).

Results

The maximum temperature of the warmest M pack, the thermostat setting and the energy consumption for each freezer is shown in Table 2. R600a values are taken from the interpolated results.

Refrigerant	R12	R600a
Thermostat setting	~5	~5
Maximum M-pack temperature	-18.2	-18.0
Average fridge temperature	4.5	4.9
Compressor run time %	36.2	38.6
Energy Consumption kWh/24h	1.036	0.9482

Table 2 The maximum temperature of the warmest pack, the thermostat setting and the energy consumption for the R12 and the R600a freezers.

The warmest M pack was positioned in the left of the top layer of the front stack in the highest drawer of the freezer. The warmest of the three temperatures measured in the fresh food storage compartment was the one nearest the top.

The R600a compressor ran for 38.6% of the time and the energy consumption was 0.9482 kWh/24h. The R12 compressor ran for 36.2% of the time and the energy consumption was 1.036 kWh/24h. The converted R600a freezer used 8.5% less energy than the R12 freezer.

Conclusions

The energy consumption of the converted R600a freezer was 8.5 % less than that of the R12 freezer when measured according to ISO 8187.

The energy consumption of the R600a freezer was 0.9482 kWh/24h.

References

(1) Conversion of a Little Swan BCD 218 Fridge-Freezer from R12 to R600a. Pull down and continuos running tests, capillary tube and refrigerant charge optimisation. FRPERC University of Bristol. June 2002.

(2) Conversion of a Little Swan BCD 218 Fridge-Freezer from R12 to R600a. Storage tests at 16 and 32°C. FRPERC University of Bristol. June 2002.

Conversion of a Little Swan BCD 218 Domestic Fridge-Freezer from R12 to R600a

Specification of converted fridge-freezer

FOOD REFRIGERATION AND PROCESS ENGINEERING RESEARCH CENTRE

Food Refrigeration and Process Engineering Research Centre (FRPERC)

Churchill Building
Langford
Bristol
BS40 5DU UK

Tel +44 (0)117 928 9239
Fax +44 (0)117 928 9314
e-mail frperc-bristol@bristol.ac.uk

General Introduction

Domestic freezer manufacturers have for the past 50 years been using R12 as the refrigerant. In Little Swan this refrigerant is now being phased out as it is environmentally harmful. R600a has been identified as the replacement. This study was to redesign one of Little Swan's freezers, a BCD 218, to convert it from R12 to R600a. The brief was that its performance should be the same or better than the R12 model and as few changes as possible were to be made. It was expected that only the compressor, capillary tube and the amount of charge would need to be changed. Some alterations may need to be made to the electrical switches and lights to comply with hydrocarbon safety regulations.

Introduction to this specification

This report gives the specification for the components of the BCD 218 freezer that need to be changed to convert it from R12 to R600a.

Specification of altered components

Compressor:	R12	R600a
Manufacturer	National	Dong Bei
Type	D66L15RAX5	QD88YG
Displacement (cc)	6.6	8.8
ASHRAE Capacity at -23.3°C (W)	180	160
Input power at -23.3 °C (W)	136	101
Voltage/Frequency	220V/50Hz.	220V/50Hz.

Capillary tube:	R12	R600a
Length m	2.5	3.95
Inside diameter mm	0.68	0.8
N2 flow rate l/m*		7.65

*values measured on test refrigerators

The new capillary tube was coiled 21 times around a 60mm length of the suction line in addition to the suction liquid heat exchanger fitted at the factory.

Charge	R12	R600a
Refrigerant charge (g)	170	62

Tests

Pulldown, storage and energy consumption Tests have been carried out (1, 2 & 3).

When the freezers operated in ambient temperatures of 32 and 16°C (climate class N), the storage temperature of food in the converted R600a freezer was colder than –18°C and the freezer can be classified as ***.

The energy consumption of the converted R600a freezer was 8.5% less than that of the R12 freezer when measured according to ISO8187. The energy consumption of the R600a freezer was 0.9482kWh/24h compared to 1.036kWh/24h for the R12 freezer.

References

(1) Conversion of a Little Swan BCD 218 refrigerator-freezer from R12 to R600a - Pulldown and continuos running tests, capillary tube and refrigerant charge optimisation. FRPERC University of Bristol. June 2002.

(2) Conversion of a Little Swan BCD 218 refrigerator-freezer from R12 to R600a – Storage tests at 16 and 32°C. FRPERC University of Bristol. June 2002.

(3) Conversion of a Little Swan BCD 218 refrigerator-freezer from R12 to R600a – Energy consumption test. FRPERC University of Bristol. June 2002.

Conversion of a Little Swan BCD218 Fridge Freezer from R12 to R600a

Pull-down and continuous running tests

Capillary tube and refrigerant charge optimisation

FOOD REFRIGERATION AND PROCESS ENGINEERING RESEARCH CENTRE

Food Refrigeration and Process Engineering Research Centre (FR&PERC)

Churchill Building
Langford
Bristol
BS40 5DU UK
Tel +44 (0)117 928 9239
Fax +44 (0)117 928 9314
e-mail frperc-bristol@bristol.ac.uk

Summary

The optimum charge for the BCD218 fridge-freezer, when fitted with a Dong Bei QD88YG compressor and operating on R600a, is 62g of refrigerant with a capillary tube length of 3.95m and diameter of 0.8mm. This gives a similar thermal performance to the R12 model.

Introduction

Domestic freezer manufacturers have for the past 50 years been using R12 as the refrigerant. In Little Swan this refrigerant is now being phased out, as it is environmentally harmful. R600a has been identified as the replacement.
This study was to redesign one of Little Swan's fridge-freezers, a BCD218, to convert it from R12 to R600a. The brief was that its performance should be the same or better than the R12 model and as few changes as possible were to be made. It was expected that only the compressor, the capillary tube and the charge would need to be altered. Some additional alterations may be required to some electrical components in order to comply with hydrocarbon safety regulations.

Method

Two fridge-freezers Type BCD218 were used. One fridge-freezer was fitted with an R600a compressor and the other was unaltered with R12. The capillary tube brazed into the circuit by the factory was shortened in stages from 4500mm to a length of 3950mm.
In all tests the thermostat was removed to ensure continuous operation of the compressor.

	R12	R600a
Compressor:		
Manufacturer	National	Dong Bei
Type	D66L15RAX5	QD88YG
Displacement cc	6.6	8.8
ASHRAE Capacity at -23.3°C W	180	160
Input power at -23.3 °C W	136	101
Voltage/Frequency	220V/50Hz.	220V/50Hz.
Capillary tube (final size):		
Length m	2.5	3.95
Inside diameter mm	0.68	0.8
N2 flow rate l/m*		7.65

Table 1. System information
***Values measured on test refrigerators.**

In all tests the thermostat was removed from the cabinet to ensure continuous operation of the compressor.

The converted R600a fridge-freezer and the un-touched R12 fridge-freezer were both placed in an insulated temperature controlled room on a test platform in accordance with ISO Standard 8187.

The room was controlled to an ambient temperature of 32°C, the warmest temperature for climate class N. Constant airflow was achieved by setting a fan in the room to distribute the air evenly.

In accordance with the Standard, the test platform was 0.3m above the floor and had three sides, which extended 0.3m above the top of the fridge-freezer. The sidepieces extended 0.3m out from the back piece and 0.3m from the fridge-freezer sides. The fridge-freezer was placed on the platform with its back in direct contact with the rear surface of the platform, (Figure 1). The whole platform was painted a dull black.

Initially the fridge-freezer was approximately equalised in the test room. It was then started and run continuously until the measured temperatures were steady. These values were then recorded. The charge or capillary tube was then altered and a similar pull-down test was conducted until optimum values for charge and capillary tube length were obtained.

Instrumentation

The fridge-freezers had T-type thermocouples placed around the refrigerant circuit as shown in Figure 2. The thermocouples were held in contact with the pipes by tape and insulated with 25mm of closed cell insulation. Where insulation had been cut away to gain access to the evaporator the walls were refilled with expanded polyurethane foam. Thermocouples were positioned at the geometric centres of the freezer and fresh food storage compartments. This gave representative temperatures inside the frozen and refrigerated compartments.

Electrical power to the compressor was measured with a Northern Design PEA200, fitted with a 2 Amp current transformer, measuring the true power, current and voltage. The energy consumption was measured over the test period.

A Datascan module connected to a PC running Labtech software was used to record the results.

Results

The results of the tests are reported in chronological order.

Data from optimisation tests

Steady temperatures at the end of the pulldown test.

Date	R12	14-4-02	17-4-02	19-4-02	12-5-02
Charge	170g	62g	62g	62g	62g
Length of capillary	2.5m	3.0m 0.68 dia.	4.5m 0.8 dia.	4.5m 0.8 dia.	4.25m 0.8 dia.
Evaporator start	-39.2	-34.3	-35.3	-36.4	-36.5
Mid way Evaporator	-39.0	-34.2	-34.1	-35.6	-33.5
Evaporator end	-38.0	-33.3	-34.1	-35.5	-32.7
Accumulator end	-35.2	-32.8	-33.2	-34.9	-31.9
Suction line	28.4	18.7	16.7	17.3	17.7
Discharge line	75.9	68.8	67.2	69.5	73.3
Condenser	37.2	42.0	41.5	40.1	41.1
Filter entry	35.0	35.0	35.3	35.5	32.7
Filter exit	34.9	34.3	33.4	34.2	31.2
Superheat	1.2	1.1	1.1	0.9	3.9
Sub-cooling	2.2	7.0	6.2	4.6	8.4

Results of the first test showed that excessive liquid was being held back in the condenser by the capillary tube. A shorter or larger diameter capillary was therefore required.
The cooler suction temperature also suggested improvement was required with the suction liquid heat exchange.

A 0.8mm diameter capillary tube of length 4.5m was fitted. The new capillary tube was coiled 21 times around a 60mm length of the suction line. This was tested on the 17-4-02.

The sub-cooling was still excessive with the new capillary, but the fridge was still being controlled on the thermostat. The test was repeated on the 19th to confirm the values.

The capillary tube was shortened by 250mm, and retested on the 12th May. The increase in subcooling and superheat was assumed to be due to air in the condenser.

Date	R12	12-5-02	13-5-02	14-5-02	15-5-02	22-5-02
Charge	170g	62g	62g	30g	54g	62g
Length of capillary	2.5m	4.25mx0.8ϕ	4.25mx0.8ϕ	4.25mx0.8ϕ	4.25mx0.8ϕ	4.25mx0.8ϕ
Evaporator start	-39.2	-36.5	-35.6	-40.6	-36.5	-36.8
Mid way Evaporator	-39.0	-33.5	-35.1	-28.8	-35.8	-36.4
Evaporator end	-38.0	-32.7	-35.7	16.7	-29.3	-36.7
Accumulator end	-35.2	-31.9	-34.6	16.8	-29.3	-35.7
Suction line	28.4	17.7	17.4	24.7	19.8	17.2
Discharge line	75.9	73.3	69	62.9	69.0	67.0
Condenser	37.2	41.1	39.3	36.9	41.2	38.4
Filter entry	35.0	32.7	36.4	34.2	32.7	35.9
Filter exit	34.9	31.2	36.2	34.1	32.3	35.3
Superheat	1.2	3.9	0.1	57.3	7.2	0.1
Sub-cooling	2.2	8.4	2.9	2.7	8.5	2.5

The filter dryer was replaced and a further 100mm of capillary was removed. The retest on the 13th May showed that the performance of the unit was then near optimised. 2.9'C of sub-cooling in the condenser denoted excessive liquid being held back by the capillary tube. In order to fully optimise the unit, the capillary tube needed to be shortened further.

The test on the 14 May showed that, despite the massive undercharge causing 57.3'C of superheat, the liquid was still backing up in the condenser. This confirmed that the capillary tube would need to be shortened.

	R12	R600a
Evaporator °C	-39.18	-36.8
Evaporator end °C	-38.95	-36.4
Evaporator mid °C	-37.99	-36.7
Accumulator end °C	-35.24	-35.7
Compressor suction °C	28.43	17.2
Compressor discharge °C	75.87	67.0
Condenser °C	37.19	38.4
Filter entry °C	35.00	35.9
Filter exit °C	34.87	35.3
Sub-cooling °C	1.19	0.1
Superheat at evaporator exit °C	2.19	2.5
Fridge temperature °C	-2.35	0.5
Freezer temperature °C	-38.12	-30.4
Suction line temp increase °C		

Table.2 Temperatures at steady state during continuous running.

With the shorter capillary and the larger charge, 15-5-02, the superheat fell, but there was still a large amount of sub-cooling in the condenser. It was possible that only gas was going round the circuit, if the charge was too small, or that the thermocouples were not reading correctly.

On 22-5-02, the larger charge resulted in a decrease in both sub-cooling in the condenser and superheat at the end of the evaporator.

On the 22-5-02, the results achieved were considered acceptable. The evaporating and condensing temperatures were similar to those on the original R12 version (Table 2).

DISCUSSION

The thermostats fitted to the converted R600a fridge-freezers should be of class N, non-sparking, unless the box into which they are sealed could be proved to be adequate to prevent any R600a refrigerant that may leak from the refrigeration circuit, from entering. See the document sent earlier on "The safety of domestic refrigerators and freezers with flammable refrigerants" for details.

The easiest changes to recognise in the temperatures measured were the superheat at the evaporator exit, and the sub-cooling across the condenser. Optimum performance would occur when there is between 1 and 2°C sub-cooling and 0°C superheat.

Conclusions

The chosen compressor was the Dong Bei QD88YG. With this compressor, the optimum charge is 62 g of R600a. The optimum capillary tube for this system had a length of 3.95m and an internal diameter 0.8mm.

Figures

Figure 1. Positioning of fridge-freezer on test platform.

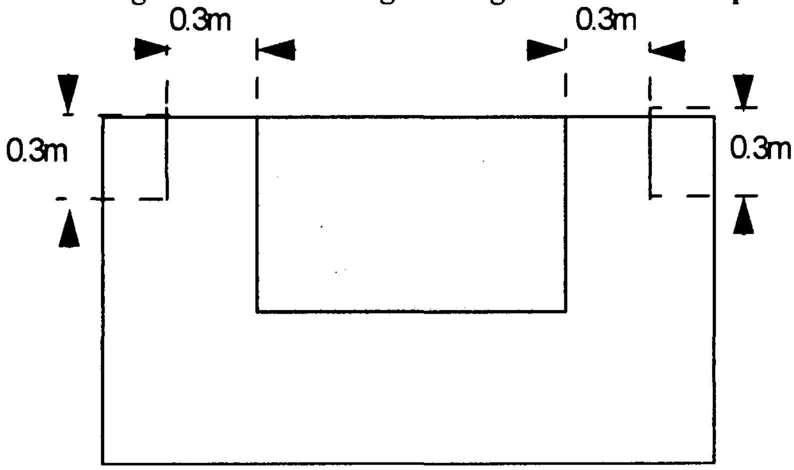
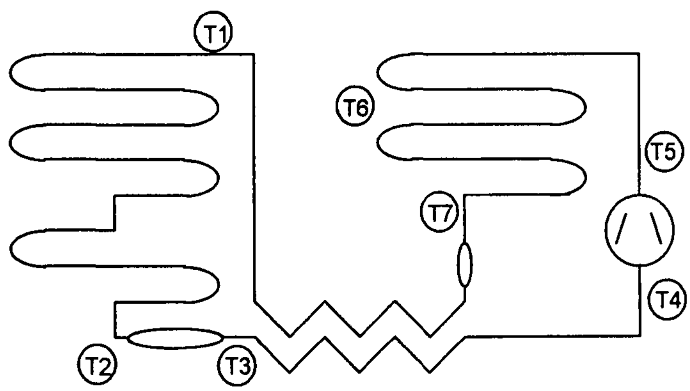


Figure 2. Positioning of thermocouples on system.



Key

T1	Evaporator start
T2	Evaporator end
T3	Accumulator end
T4	Suction line
T5	Discharge line
T6	Condenser
T7	Filter entry

Conversion of a Little Swan BCD 218 Fridge-Freezer from R12 to R600a

Storage Tests at 16 & 32°C

FOOD REFRIGERATION AND PROCESS ENGINEERING RESEARCH CENTRE

Food Refrigeration and Process Engineering Research Centre (FR&PERC)

Churchill Building
Langford
Bristol
BS40 5DU UK
Tel +44 (0)117 928 9239
Fax +44 (0)117 928 9314
e-mail frperc-bristol@bristol.ac.uk

Summary

The purpose of these tests was to measure the storage temperature of the BCD 218 to verify that it complied with ISO 8187. One fridge-freezer was operated with R12 and one with R600a, in ambient temperatures of 32 and 16°C.

In an ambient temperature of 16°C, the coldest ambient temperature for climate class N, the warmest M-pack in the R600a freezer was –20.3°C. The thermostat was set to 5, in order to maintain fridge temperatures between 0 and 10°C with an average of less than 5°C, in accordance with the Standard.
The R12 Fridge-Freezer was unable to maintain ISO Standard conditions at an ambient temperature of 16°C.

When operating in an ambient temperature of 32°C, the warmest ambient temperature for climate class N, the warmest M pack in the converted freezer was –19.5°C. The thermostat was set to 5, in order to maintain fridge temperatures between 0 and 10°C with an average of less than 5°C, in accordance with the Standard.

The converted R600a Fridge-Freezer can be rated as suitable for both fresh food storage and as a 3 Star freezer.

General Introduction

Domestic freezer manufacturers have for the past 50 years been using R12 as the refrigerant. In Little Swan this refrigerant is now being phased out, as it is environmentally harmful. R600a has been chosen as the replacement. The aim was to redesign one of Little Swan's freezers, a BCD 218, to convert it from R12 to R600a. The brief was that its performance should be the same or better than with R12 and as few changes as possible were to be made. It was expected that only the compressor, capillary tube and charge would need to be changed.

Introduction to this report

A previous report covers the optimisation of the size of the capillary tube and charge in the R600a version of the BCD 218 freezer (1). The aim of the tests described in this report was to measure the storage temperature of the converted R600a and the original R12 freezers at the warmest and coldest ambient temperature according to the method described in ISO 8187 (The Standard) for climate class N (32°C and 16°C). The test was first carried out at 32°C with the freezers loaded according to the Standard. With the compressor running continuously the temperature of the warmest M pack had to be colder than -18°C.

Method

The two freezers used in the pull down and continuous running tests (1) were used for these tests. Both were BCD 218s. The R600a freezer had the R600a compressor and the optimum capillary tube and charge reported in the previous tests (Table 1).

	R12	R600a
Compressor:		
Manufacturer	National	Dong Bei
Type	D66L15RAX5	QD88YG
Displacement cc	6.6	8.8
ASHRAE Capacity at -23.3°C W	180	160
Input power at -23.3 °C W	136	101
Voltage/Frequency	220V/50Hz.	220V/50Hz.
Capillary tube:		
Length m	2.5	3.95
Inside diameter mm	0.68	0.8
N2 flow rate l/m*		7.65
Charge g	170	62

Table 1 Refrigeration system information for the freezers under test. *values measured on test refrigerators

Ambient temperature 32°C

The ambient temperature in the test room was 32±0.5°C (climate class N). The temperature gradient between the floor and the ceiling was less than 2°C/m.

The tests were carried out with the frozen food storage compartments loaded with M packs. The chilled storage compartment temperatures were measured with thermocouples placed inside brass blocks (Figure 1). The loading was carried out in accordance with the Standard.

For each test the freezer was run on the coldest thermostat setting until the temperatures over repeated cycles were stable as defined in the Standard. Each test continued for a minimum of 24 hours.

Ambient temperature 16°C

The ambient temperature in the test room was 16±0.5°C (climate class N). The temperature gradient between the floor and the ceiling was less than 2°C/m.

The tests were carried out with the frozen food storage compartments loaded with Tylose M packs. The chilled storage compartment temperatures were measured with thermocouples placed inside brass blocks (Figure 1). The loading was carried out in accordance with the Standard.

For each test the freezer was run on the coldest thermostat setting until the temperatures over repeated cycles were stable as defined in the Standard. Each test continued for a minimum of 24 hours.

Instrumentation

Temperatures were measured at the positions shown in Figure 2 of Reference 1 (Pull down and continuous running tests).
The temperatures of the M packs and brass blocks were measured in their geometric centres with thermocouples and were recorded on the data logger with the other temperatures (1).

Results

The temperatures of the M packs after stabilisation are shown in Table 2.

		R12		R600a	
Ambient Temp.		16°C	32°C	16°C	32°C
B1	Min	1.0	5.5	2.6	5.7
	Max	3.6	8.1	4.3	8.4
	Average	2.0	6.8	3.4	7.2
B2	Min	0.2	3.7	1.0	3.2
	Max	2.6	6.3	2.9	6.3
	Average	1.2	5.0	1.9	4.8
B3	Min	-2.2	0.2	0.0	1.3
	Max	1.9	5.2	2.4	5.4
	Average	-0.1	2.6	1.1	3.2
Fridge	Average	1.0	4.8	2.1	5.0
M1	Min	-18.5	-23.2	-20.8	-21.2
	Max	-17.7	-22.5	-20.3	-19.5
	Average	-18.2	-22.9	-20.6	-20.7
M2	Min	-18.8	-23.7	-21.5	-22.3
	Max	-18.2	-23.0	-20.9	-20.6
	Average	-18.5	-23.5	-21.2	-21.8
M3	Min	-20.0	-23.7	-23.0	-23.1
	Max	-19.1	-23.0	-22.5	-21.4
	Average	-19.6	-23.4	-22.7	-22.6
M4	Min	-20.5	-24.5	-22.7	-22.8
	Max	-19.8	-23.8	-22.3	-21.1
	Average	-20.2	-24.2	-22.5	-22.2

Table 2 The warmest measured temperatures at each point during the storage tests on the BCD 218 freezers. Figure 1 shows the location of each position within the freezer.

In an ambient of 32°C, the warmest M pack in the R600a freezer was –19.5°C, measured at position M1 at the front, top left corner of the top drawer. The thermostat was set to 5.

When operating in an ambient temperature of 16°C the warmest M pack in the converted freezer, position M1, was –20.3°C. The thermostat was set to 5.

Conclusions

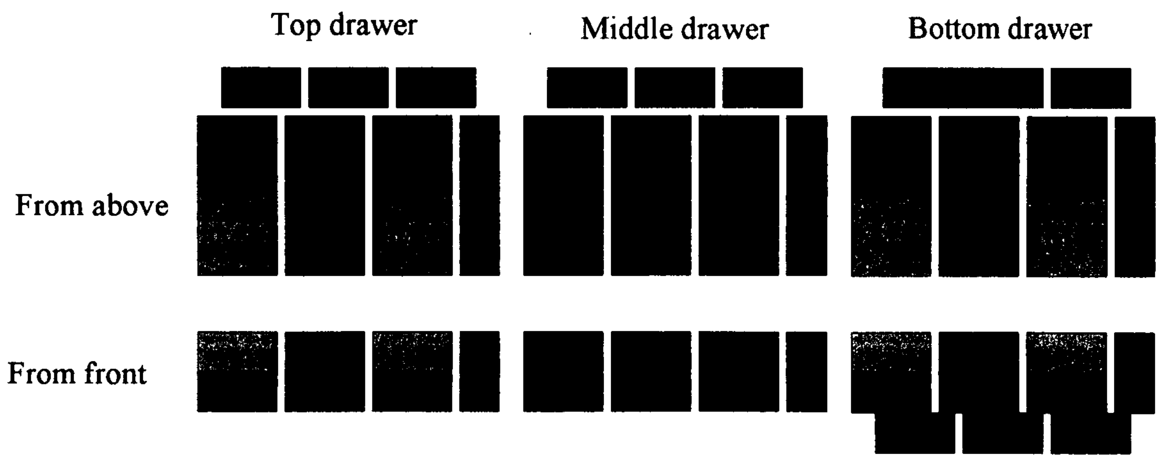
When the freezers operated in ambient temperatures of 32 and 16°C (climate class N), the performance of the converted R600a freezer was better than that of the R12 freezer.

The warmest M pack in each test on the converted freezer was colder than –18°C, therefore the freezer was classified as 3 Star.

References

(1) Conversion of a Little Swan BCD 218 Fridge-Freezer from R12 to R600a - Pull down and continuos running tests, capillary tube and refrigerant charge optimisation. FRPERC University of Bristol. June 2002.

Figure 1



Plan and elevation of the BCD 218 freezer showing the position of the M packs during the storage temperature tests.

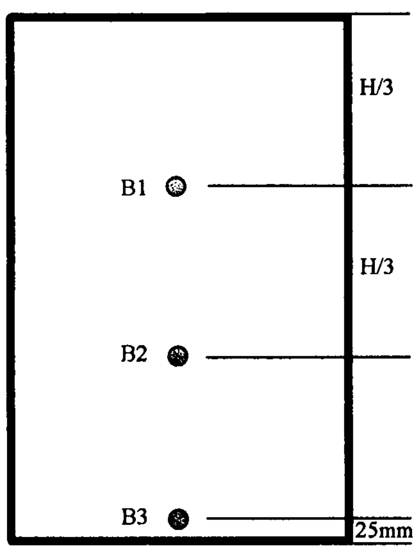


Diagram of copper block locations in the refrigerator compartment of the BCD 218 during the storage temperature tests.