1 - INTRODUCTION

The use of flammable refrigerants in hermetic domestic refrigeration systems was discontinued after the appearance and large scale production of CFC refrigerants. CFC refrigerants became the refrigerants of choice because they are low in cost, non-toxic and are not flammable.

However, studies have shown that CFCs have damaged, and continue to threaten, the Earth's delicate ozone layer. In light of this, the Montreal Protocol was established to manage the discontinuation of these refrigerants.

Various alternative refrigerants to CFC12 were studied and some are now being used by the refrigeration industry worldwide. Among them, are some flammable refrigerants.

Flammable refrigerants such as (R 600a) isobutane have gained in popularity with the consumer population primary because of its environmentally benign properties. More specifically hydrocarbon refrigerants are safe to the Earth's ozone layer and are also not considered a direct contributor to the Global Warming phenomena known as the Greenhouse Effect.

The objective of this technical report is to present, in detail, the principal technical characteristics and the impacts, in both the compressor and the hermetic refrigeration system when using the alternative isobutane refrigerant.

2 - THE ISOBUTANE REFRIGERANT

Isobutane refrigerant, like other alternative refrigerants, presents some thermodynamic characteristics different from those of R 12 (see figure 1).

Figure 1 shows that isobutane (R 600a) presents lower vapour pressures than R 12 or R 134a, in the standard operational temperature range for a refrigeration system.

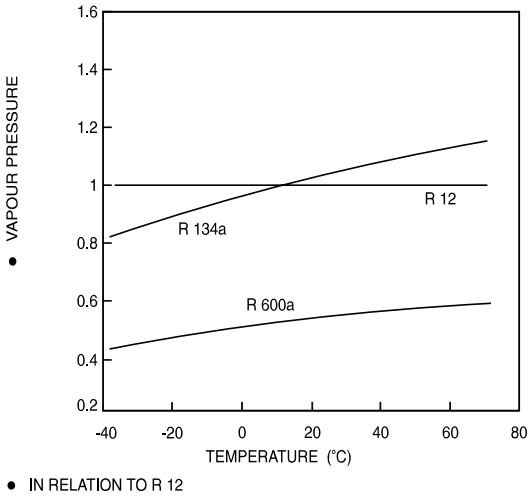

Fig.1. - Behaviour of vapor pressure of R 600a and R 134a in relation to R 12, according to temperature.

To better observe the impact of substituting R 12 for R 600a in refrigeration applications, please see the table below. The data were acquired through calorimeter tests of the EM 20NP 220-240V/50Hz operating with R 12 and its R 600a compatible equivalent.

REFRIGERANT		R 12	R 600a
COMPRESSOR		EM 20NP	EMI 20CEP
A - Displacement	cm^3	2.27	3.77
B - Evaporating Pressure (-25ºC)	bar	1.237	0.579
Condensing Pressure (55ºC)	bar	13.66	7.72
Enthalpy (-25ºC / 32ºC)	kJ/kg	375	501.5
Enthalpy (55ºC)	kJ/kg	254	224.9
Enthalpy Difference	kJ/kg	121	276.6
C - Refrigerating Capacity	W	35	34
Mass Flow Rate	kg/h	1.046	0.443
Cylinder Outlet Gas Temperature	ºC	99	87
D - Expansion Device Inlet Temperature	ºC	55	55
Specific Volume	dm^3/kg	0.841	1.960
Volume Flow	dm^3/h	0.879	0.867

Table 1 - Comparison between R 12 and R 600a

Observe in table 1, section A, that the R 600a compressor must have an increased volumetric displacement, about 65% to 70% greater than the R 12 model, to have similar levels of refrigerating capacity.

The enthalpy difference of R 600a is significantly greater than that of R 12, as can be observed in section B. Thus, a lower mass flow rate is required to obtain the same refrigerating capacity. As shown in section C of table 1, the monitored temperature at the discharge of the compressor operating with R 600a is lower than that of the R 12 model.

The conditions of the refrigerant at the inlet of the expansion device are presented in section D table 1. As can be observed, the volume flow with isobutane is around 1.3% lower than that of R 12, i.e., in principle no alterations are required in the capillary tube of refrigeration systems when isobutane is used as a substitute for R 12.

3 - COMPRESSOR SELECTION FOR R 600a

As it was previously mentioned, isobutane requires a volumetric displacements increase of 65 to 70% in relation to R 12, for a determined refrigerating capacity.

Therefore, EMBRACO compressors for R 600a have had their displacements adjusted, for the purpose of making their refrigerating capacity equivalent to R 12 or R 134a models. Interestingly enough, these internal changes have been made with no alteration to the external dimensions of the compressors.

It must be emphasized that only compressors developed for R 600a can be used with this refrigerant. The use of R 12 or R 134a compressors is definitely not advisable for applications with R 600a.

For further information on R 600a compatible compressors currently available from Embraco, please contact our sales staff at the addresses supplied at the end of this report.

4 - LUBRICATING OIL

The mineral and synthetic oils currently used in refrigeration systems with R 12 are fully compatible with R 600a and are recommended for this application.

Ester oils are also compatible with R 600a. However, this type of oil presents a higher cost, is not compatible with certain chemical compounds currently used in the manufacturing processes of compressors and components for refrigeration systems with R 12, and further requires special care in handling, due to its high moisture absorption capacity.

5 - REFRIGERATION SYSTEMS FOR R 600a

The use of isobutane in refrigeration systems presents some fundamental differences, as listed below, in relation to a system with R 12, i.e., principally in safety aspects, which are described in item 6.

5.1 - TUBING

Isobutane refrigerant is compatible with the principal metallic materials used in refrigeration systems such as steel, copper, brass and aluminum.

Elastomers such as Viton, Neoprene, Nylon, Teflon and some types of nitrile rubber are suitable for use with R 600a. However, natural rubber and silicone are not recommended.

5.2 - HEAT EXCHANGERS

Heat exchangers (condensers and evaporators) that operate trouble-free with R 12 can also be used in systems for R 600a. However, depending on the configuration of each specific type of heat exchanger, fine tunings may be required.

5.3 - CAPILLARY TUBE

As demonstrated in table 1, section D and experimentally verified, there is in principle, no alteration necessary to the capillary tube of refrigeration systems originally designed and optimized for R 12, when R 600a is used as replacement refrigerant.

5.4 - FILTER DRIER

The commonly used desiccants in filter driers of systems for R 12 (XH-5 and XH-6) and R 134a (XH-7 and XH-9) are fully compatible with R 600a and are recommended.

It is advisable to mention that a drier should always be used in refrigeration systems whether for R 600a, R 134a or R 12.

5.5 - REFRIGERANT CHARGING

In refrigeration systems that operate trouble free with R 12, the R 600a charging will be approximately 40% of the original R 12 charge.

However, this is not a general rule but serves as a preliminary estimation of the R 600a charging.

An important point to observe is the methodology used in the determination of refrigerant charging with R 600a.

Special care must be taken to avoid air infiltration into the system when small quantities of refrigerant are added through a gas cylinder in order to attain an adequate charge. This is due to the fact that systems with R 600a work with suction pressures below atmospheric pressure.

The hose which connects the gas cylinder to the process tube of the refrigeration system must be emptied each time a new quantity of R 600a is added.

When determining the refrigerant charge, the system must be emptied and the total refrigerant charge must be introduced into the system at one time.

6 - SAFETY IN REFRIGERATION SYSTEMS FOR R 600a

Concerns over the use of R 600a in systems originally designed for R 12 or R 134a is not purely and simply restricted to the change of refrigerant (as commented in item 5).

As R 600a is a flammable refrigerant, aspects related to the system's safety must be observed to insure safe operation without danger of explosion or fire.

The following recommendations encompass all the available presently known information concerning design and operational safeties required for R 600a systems.

However, it must be emphasized that each system manufacturer must carry out specific risk assessments on each product configuration to be used with R 600a, to guarantee the safety of its products.

6.1 - LEAKAGE IN THE INTERNAL COMPARTMENT OF THE SYSTEM

There is a risk of explosion in the internal compartment of the system if there are leaks of R 600a from the evaporator. These leaks, on contact with air, can form a flammable mixture. Any source of ignition (e.g. thermostat, on/ off switches, electrical resistance, etc.) coming into contact with this mixture, may produce a flame or explosion.

This possibility can be avoided or minimized through taking certain steps as described below:

a) System with evaporator outside the internal compartment.

- the use of evaporators enclosed in insulating foam, “cold-wall” type, largely used in the European market, significantly reduces the probability of a leakage reaching the internal compartment. In this case, no alteration is necessary to the electrical devices.

b) System with evaporators inside the internal compartment.

- use of evaporators with two walls (introduction of a metallic security barrier wall) is also recommended for reducing the possibility of leakages reaching the electrical components inside the internal compartment.
- should conventional evaporators be used (without the extra metallic security wall) all electrical devices must be:
  - removed from the internal compartment and placed on the external side of the system away from the evaporator or;
  - must be encapsulated or;
  - must be fire and explosion proof.

6.2 - LEAKAGE ON THE EXTERNAL SIDE OF THE SYSTEM

The possibility of an R 600a leakage on the external side of the system, sufficient to form combustible mixture with air, is very remote.

However, systems “built-in” to another structure are more susceptible to this possibility.

The compressor's electrical components, located in the posterior portion of the cabinet, may act as an ignition source if a leak occurs in the external side of the system. Compressors designated for use with hydrocarbon refrigerants should include electrical components that safeguard against this danger (i.e. components are encapsuled or fire and explosion proof).

In light of this problem, EMBRACO has researched alternatives and is producing compressors for R 600a with electrical devices that eliminate this risk of ignition.

6.3 - LEAKAGE IN THE SUCTION LINE OF THE REFRIGERATION SYSTEM

Refrigeration systems which use R 600a function, as previously mentioned, with suction pressures below the atmospheric pressure.

If there is a leak in the suction line when the compressor is operating, air is drawn into the interior of the refrigeration piping system. Also, when the compressor stops, and system pressures are allowed to equalize, the positive balanced system pressure will reverse the flow at the leak and R 600a will be forced out into atmosphere.

To obtain a flammable mixture with R 600a, it is necessary to have about 92 to 98% of air volume in the system tubing. When this occurs, the quantity of isobutane present in the system, which is already small due to its reduced gas charging, becomes so insignificant that it offers no danger of explosion.

It is advisable to mention that there are some international standards available on the safety of refrigeration systems, also for operation with flammable refrigerants.

7 - ASSEMBLING OF REFRIGERATION SYSTEMS FOR R 600a

The following recommendations must be closely adhered to when assembling refrigeration systems for R 600a:

a) It is recommended that manufacturer's of refrigeration systems utilizing flammable refrigerants such as R 600a develop accurate charging, leak testing, and system testing methods to guarantee that all necessary safety procedures have been met.

b) Adequate ventilation, mechanical if necessary, must be guaranteed in the R 600a charging area of the system. Furthermore, leakage detectors/isobutane sensitive gas sensors must be used in this area. These sensors should be installed close to floor level as R 600a is heavier than air.

c) The risk of potential electrostatic charges (which can cause sparks) accumulating in the refrigeration system must be fully avoided during the refrigerant charging process, through a correct grounding system.

d) Leakage tests in the system must be carried out using Nitrogen, or preferably Helium. The use of air for this test is definitely inadvisable and dangerous.

e) After the system has been charged with R 600a, flames must not be used for welding or brazing the system junctions or connections. For this purpose, ultrasonic welding or the LOKRING tube joining system is recommended.

f) The percentage of non condensable gases should be limited to 1%.

Note: After replacement, the compressor and it’s accessories must have proper processing, and the components must be recycled according to the material group (ferrous, non-ferrous, polymers, oils, ...) directives. These recomendations are intended to minimize the adverse impacts that may be caused to the environment.

Embraco is participating in the United Nations Global Compact.