Hermetic Refrigerating Compressors and the CFC Substitution

E. Heinzelmann
Fmbraco

M. S. Ussyk
Fmbraco

HERMETIC REFRIGERATING COMPRESSORS AND THE CFC SUBSTITUTION

ERNESTO HEINZELMANN

MARIO SERGIO USSYK

EMBRACO - EMPRESA BRASILEIRA DE COMPRESSORES S/A

P.O.BOX 027 - 89200 - JOINVILLE - SC - BRAZIL

ABSTRACT

The paper is divided into three parts. The first presents a basic criterion for determining the most feasible substitute refrigerants for CFC 12 in small refrigerating hermetic compressors. The method includes a simple analysis of some physical and thermodynamical properties of each refrigerant, within the ranges of evaporating and condensing temperatures where small refrigerating systems work. Parameters such as vapor pressure, compression ratio, final isentropic compression temperature, volumic refrigerant effect, and others permit a good relative comparison among the refrigerants.

The second part describes Embraco procedure for development of hermetic compressors adjusted to new refrigerants. Project optimization, compatibility material analysis, performance and reliability product tests, and production means are considered. A time frame is established for the procedure, from the preliminary refrigerant analysis through the production start-up.

In the last part, the strategy regarding the phase in of new environmental friendly refrigerants versus the phase out of CFC compounds is discussed. Focus is given to the differences among developed countries and developing countries, where Brazil is used as an example.

PRELIMINARY ANALYSIS OF THE REFRIGERANTS

The following analysis must be seen only as a first step in the search for, and determination of, a new refrigerant to substitute CFC 12 in domestic refrigeration. This procedure is aimed at thermodynamic analysis from the point of view of the compressor. New concepts are not introduced, trying only to bring together and review some of the parameters presented in refrigeration books that have significant influence on the performance of refrigerating hermetic compressors. The proposed analysis is qualitative and it only indicates favourable and unfavourable aspects about the application of new refrigerants as substitutes for CFC 12. However, it permits some savings in time and expense by avoiding deep investigation, expensive experiments and computer simulations of refrigerants that can be rapidly eliminated in this preliminary phase.

Obviously, the refrigerants with high potential to substitute CFC 12 require extended investigations, and they certainly would not be excluded in this superficial analysis. However, for these refrigerants some performance tendencies are already clearly shown, simplifying the following stages of analysis.

It is important that the parameters not be considered at only one specific running condition, but over all the operating range of the systems, since compressor performance is highly affected by the evaporating condition. Therefore, the following parameters are plotted as a function of the evaporating range (-35 to 15°C), for a constant condensing condition. The analysis may be enriched also by varying the condensing condition, although this is not within the scope of this work.

For example, the following comments referring to the comparison of HCFC 22, HFC 134a and HFC 152a refrigerants with CFC 12 can be made.

Figures 1 and 2 present a COP comparison among the different refrigerants under two distinct evaporating conditions. The first one, considers the refrigerant effect without superheating, while the second one demonstrates this effect with superheating at 32°C. In both cases, the initial compression vapor temperature is 32°C. The relative position of the refrigerants are distinct on both graphs at low evaporating temperatures. In the first graph, for example, HFC 152a is slightly above all the others while in the second graph (with superheating) HCFC 22 is slightly below all the others. Based on these facts, we may say that the COP parameter is not sufficient for the qualification of a refrigerant, even in a preliminary analysis. Hermetic compressors are characterized by the high interaction of many simultaneous phenomena. Suction gas superheating for instance, alters significantly the final performance of the compressor in such a way that small differences like the ones presented in the COP may be easily misunderstood. It is necessary to search for other parameters for analysis.

Looking at the vapor pressure curve (figure 3), some differences may already be seen. HCFC 22 has a vapor curve above CFC 12, while HFC 134a has a curve very close to CFC 12. HFC 152a has a curve constantly lower than CFC 12. From this figure we may prematurely conclude that HFC 134a is the most appropriate substitute for CFC 12.

However, based on the vapor pressure curve we may obtain a more detailed analysis using two other parameters of comparison: the difference of compressor pressure between suction and discharge and the compression ratio.

The first parameter is represented in figure 4. The pressure difference between the condensing and the evaporating temperatures has an impact on the bearing design and leakages in the compressor. Higher pressure difference requires strengthened gaskets, valves and other mechanical components, as well as bigger bearings.

Thicker valves as well as bigger bearings reduces compressor efficiency. The starting ability of the compressor during cycling is also affected by higher pressure differences, requiring higher starting torque motors which mean less efficient motors.

In figure 4 we may observe that HCFC 22 is far above the others, including CFC 12. HFC 134a, although closer to CFC 12, is also above, which is not favourable.

Figure 5 presents the second parameter related to the vapor pressure curve. This is an extremely important parameter for the performance of the compressor. It directly affects the volumetric efficiency as well as the compression work. The lower the compression ratios are, the better mechanical efficiencies we achieve.

At higner evaporating temperatures, all refrigerants tend to a common value. For lower evaporating temperatures, the refrigerants present significant differences in compression ratios.

If we plot the compression ratio data from figure 5 relative to CFC 12, which is done in figure 6, it is easy to notice that HFC 152a and especially HFC 134a have increasing values in relation to CFC 12, as evaporating temperature decreases. HFC 134a for example, has a compression ratio 30% higher than CFC 12 at an evaporating temperature of -35° C. This indicates that the performance of HFC 134a gets sensibly worse in systems that operate with low evaporating temperatures.

From figure 6 we may also notice that HCFC 22 has a compression ratio very close to CFC 12 over the whole range.

Another characteristic which may be considered is the refrigerant temperature at the end of compression. For small hermetic compressors we may assume an isentropic compression. Figure 7 indicates the final isentropic temperatures for the refrigerants in question.

The increase of the vapor temperature during compression is a fact with a considerable impact on compressor performance and reliability. High compression temperatures cause oil degradation, valve cooking and carbonization. Besides that, it increases the heat transference potential in the compressor, tending to increase the temperatures of the suction vapor and the electric motor.

Low evaporating temperatures, high condensing temperatures and gas superheating, increase the final vapor compression temperature.

Figure 7 shows that for high evaporating temperatures, the difference in the final compression temperature is small. By decreasing the evaporating temperature, the difference between the refrigerants is well characterized.

HFC 134a has the best performance, just below CFC 12. On the other hand, HCFC 22 and HFC 152a refrigerants have very high temperatures at the end of compression.

The next parameter to be considered is the specific refrigerating effect, understood as the specific enthalpy difference in the evaporator. It determines the mass flow to produce a desired refrigeration capacity. The higher the specific refrigerating effect, the lower the mass flow must be.

The specific refrigerating effect varies drastically with the liquid subcooling and vapor superheating temperatures and not that much with the evaporating temperature. As may be seen in figure 8, this parameter also varies significantly from one refrigerant to another.

All the refrigerants here analyzed, have specific refrigerating effects larger than CFC 12. This can be interpreted as meaning that to obtain the same refrigerating capacity, the refrigerating systems will operate with lower mass flow. In the extreme case, for HFC 152a, the mass flow will be approximately half of that of CFC 12.

Such significant variations imply major redesign of the valve system as well as the compressor mufflers to adapt them to the very low mass flows.

Finally, the last characteristic to be considered is the volumic refrigerating effect as cited in reference (1).

The volumic refrigerating effect is the specific refrigerating effect divided by the specific vapor volume under a suction condition. It determines the compressor displacement necessary to produce a certain refrigerating capacity. The higher the volumic refrigerating effect, the lower the compressor displacement must be.

Figure 9 shows that the curve for HCFC 22 is higher than the group of other refrigerant curves, including CFC 12. When the volumic refrigerating effect is plotted in relation to CFC 12, as in figure 10, we observe that to keep the same refrigerating capacity, a compressor which operates with HCFC 22 must have a displacement close to half of that of a compressor operating with CFC 12. This is an enormous barrier to use of HCFC 22, since domestic refrigerating compressors already have a small displacement and it would be practically impossible to reduce them to that level.

On the other hand, HFC 152a would require a displacement approximately 10% larger than CFC 12 which is easier to obtain. It is interesting to notice that the behaviour of HFC 134a crosses the CFC 12 curve. Again, this indicates the inferior performance of HFC 134a for low evaporating temperatures. For example, roughly saying, if the displacement of the compressor is calculated for the same capacity as CFC 12 at an evaporating temperature of -10°C, the compressor will have approximately 10% less capacity with HFC 134a when operating at -35°C.

From what has been presented above, we may affirm that HCFC 22 has no chance to replace CFC 12 for domestic refrigerating applications with low evaporating temperatures. The volumic refrigerating effect curve demonstrates that it is practically impossible to adapt small compressors to the use of HCFC 22. At the same time, the curves of pressure difference between suction and discharge, as well as the final compression temperature, also play a very unfavourable role.

Concerning the other refrigerants, HFC 134a and HFC 152a, it was not possible to obtain expressive arguments which could lead to the elimination of any of these candidates. Although some further comments can be made.

HFC 134a showed deficiencies at low evaporating temperatures. The high compression ratio is the main negative factor. Higher pressure difference between suction and discharge and the tendency of the volumic refrigerating effect curve, may also contribute negatively. As a positive aspect, the low temperature at the end of compression may be mentioned.

HFC 152a does not have such apparent disadvantages as HFC 134a for low evaporating temperatures. On the other hand, the reduced mass flow certainly will demand changes in the compressor, as well as the high discharge temperature, which acts negatively for this refrigerant.

DEVELOPMENT OF COMPRESSORS APPLICABLE TO NEW REFRIGERANTS

For many decades domestic refrigeration has been working with CFC 12 as a refrigerating fluid. There were no doubts about the advantages of this product, so that it is now used by all of the manufacturers.

In this case, substitution can not be seen as a simple change from CFC 12 to another refrigerant, keeping the same design and immediately obtaining favourable results.

The impact of this change is enormous. Several features must be considered together: energy consumption, comfort (noise), safety (toxicity/flammability), availability, adjustment to existing products, and, obviously, environmental aggressiveness level (ODP, GWP). Besides these, the cost parameter can not be neglected, specially in developing countries.

Up to the moment, there is no final decision on the CFC 12 substitute for domestic and small comercial refrigeration. On the other hand, the CFC 12 phase out pressures have increased considerably.

Based on the above, Embraco was compelled to establish a very flexible compressor development program applicable to new refrigerants.

Each refrigerant that appears as a probable CFC 12 substitute iniciates a route, such as the one indicated in figure 11. The program has some decision steps where the results of each concluded stage are analyzed and the decision on the continuity or not of the refrigerant in the development program is taken.

The first step, "Refrigerant Preliminary Analysis", is nothing more than what was presented in the first part of this paper. It is a quick task, where only some knowledge of the physical and thermodynamical properties of the refrigerant are required. Once the refrigerant is approved, it proceeds to the third step.

Step 3, "Initial Experimental Analysis", begins with the availability of refrigerant and oil samples. Analysis of solubility and miscibility of the refrigerant/oil mixture is made. Compatibility tests of materials with the new refrigerant and oil, are started, also. First, life and wear tests are also carried out. Compressor performance in calorimeter and noise tests, starting ability and stalling is evaluated. Experiments such as the aquisition of the PxV diagram, valve motions and the compressor thermal profile are important data to be analysed. When this step is concluded, it is possible to have a very precise idea of the impact caused by the new refrigerant in the actual compressors designed for CFC 12.

It is time now to proceed to the second and important decision. Does the refrigerant being analysed really have possibilities to replace CFC 12 with some advantages? Only the refrigerants with high potential should proceed from this point.

When the refrigerant is approved in decision step 4, it is time to begin the "Prototype Definition". Product requirements are established. The compressor must be redesigned according to simulation programs and experiments.Tests are made with different prototype configurations. Manufacturing feasibility analysis and prototype compressor components design are done.

In sequence, step 6 - "Prototype Tests", compressor prototype lots are manufactured to check the reliability, performance and application of the product. The time estimated for steps 5 and 6 is 12 months, approximately.

In step 7, it is time to decide on the manufacturing of compressors according to the new refrigerant. Having reached a positive decision, the "Product Development" - step 8 - is initiated.

The product development step consists in final product design, supplier development and production facilities adjustments.

Concluding, product approval tests are done.

Finally, step 9 covers the starting of pilot production up to normal production. Steps 8 and 9 should last at least 12 months.

The overall time estimated for the complete development program is from 24 to 38 months.

Nevertheless, it cannot be forgotten that the choice of a new refrigerant is not an individual decision. Compressor manufacturers, refrigeration appliance producers, refrigerant manufacturers and governments play a very important role in this scenario. The overall time expectancy depends on how quickly and how precisely the decisions are made.

CFC REPLACEMENT IN DEVELOPING COUNTRIES

In developed countries the consumption of CFC's is distributed over many different applications. These applications were developed for different reasons, normally linked to comfort parameters (like Car A.C., aerosols, home insulation, etc.), or to processing technologies (food processing, cleaning processes, tobacco puffing, etc.). Because of the cost associated with such applications, or due to the lack of available technology, many of these applications are used on a very small scale or not at all in developing countries. In fact, the use of CFC's in developing countries is normally directed to basic applications, such as the refrigeration industry. We may mention some examples, using Brazil as a reference for a developing country.

- The total CFC consumption in Brazil is around 10,000 ton/year, which represents less than 1% of the world consumption. Assuming a population of 150 million inhabitants, Brazilian consumption reaches 0.07kg CFC/inhabitants year.
  In comparison, the U.S.A., where CFC consumption is approximately 300,000 ton/year - roughly 1/4 of the world total consumption, per capita consumption is 18 times the Brazilian one, reaching 1.25kg CFC/inhabitant year assuming the U.S. population as 240 millions.
- In the U.S.A., approximately 20% of CFC consumption is used in automobile air conditioners. In Brazil, despite its tropical climate, this application represents less than 5% of Brazilian CFC consumption.
- In Western Europe, 40% of CFC consumption is used for aerosols. This application was never representative in Brazil and the use is restricted to essential medicinal application since 1988.
- In Brazil, CFC consumption for domestic refrigeration and small commercial units, which use CFC 12 in the system and CFC 11 for foaming, is approximately 25% of total annual CFC consumption. Considering the developed countries, this figure is not higher than 5%.
- 70% of the Brazilian home refrigeration market is concentrated in one-door refrigerators with an internal volume up to 290 liters. Small and simple refrigerators have the advantage of using smaller quantities of CFC's and lower power consumption. Many of the one-door refrigerators produced in Brazil are able to meet the 1990 U.S. DOE standards.
- Finally, the increase in the product costs which will occur through the use of alternative refrigerants may reduce many people's ability to buy their first refrigerator, in a market which is far from saturation.

The Montreal Protocol recognized this situation by allowing the countries with a consumption of less than 0.3kg per capita to enforce the established restrictions within 10 years or upon reaching the limit of 0.3kg per capita, whichever occurs first. Such protection should be kept in the revision of the Protocol to allow for the time necessary to absorb the new technologies involved with CFC replacement, particularly in view of the small contribution to ozone depletion caused by developing countries.

Up to now there is no clear definition of which refrigerants will replace the ones now being used for domestic refrigeration. It may be that in Europe, for instance, HFC 134a will replace CFC 12 while in the U.S.A., due to the energy consumption penalty being reported, probably another refrigerant will be adopted.

Developing coutries, with low financial and technical resources, and a small countribution to the ozone depletion problem, should be allowed the chance and time to adapt their internal market to the best alternative, already proven in developed countries. The developed countries should support the developing countries in applying the required technology. This is also being considered in the Montreal Protocol and will certainly help to phase out CFC usage worldwide. This support should not be restricted to just financing industrial projects, which may be successful or not, but to promoting the effective transfer of know-why.

Brazilian production of hermetic compressors for refrigerators and freezers in 1989 was over 11 million units. Approximately 60% of this volume was directed to the external market. Exports of refrigerators and freezers are also increasing year by year. Most of these exports are to developed countries, which have very strong programs for replacement of CFC's in the 1993-1998 time frame. In some cases, mainly in the U.S.A., besides the restriction on using CFC's, stricter energy standards are already defined. For Brazil, this situation can be considered as a driving force to develop the technology for using new refrigerants in the same time frame as the developed countries.

The compressor and refrigeration industries have long recognized the necessity of following international targets. Embraco has nearly 8% of the world market in hermetic compressors for refrigeration, with exports concentrated in large volumes to the U.S.A. and Europe. We certainly have to follow international trends and we are sure that we can be successful.

REFERENCE

1. Gosney, W.B. - Principles of Refrigeration, Cambridge University Press 1982, 178.

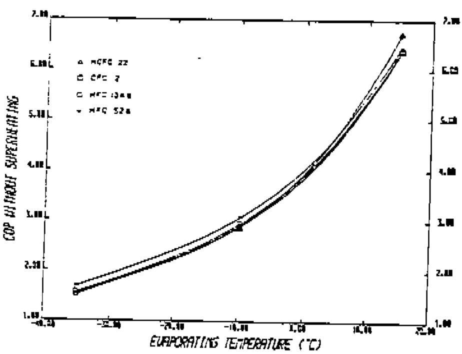


FIGURE 1 - COP of the refrigerating cycle under different evaporating temperatures, considering 55°C of condensing temperature, isentropic compression, and 32° C of initial compression vapor temperature. Evaporating with 32° C subcooling and without superheating.

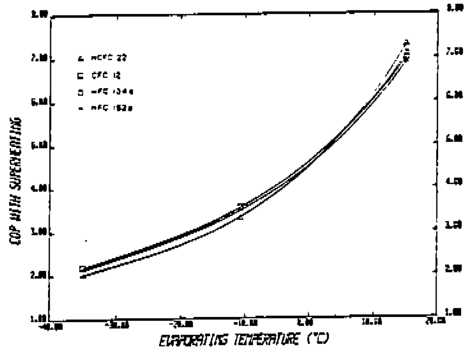


FIGURE 2 - COP of the refrigerating cycle under different evaporating temperatures, considering 55°C of condensing temperature, isentropic compression, and 32 °C of initial compression vapor temperature. Evaporating with 32° C subcooling, and 32° C superheating.

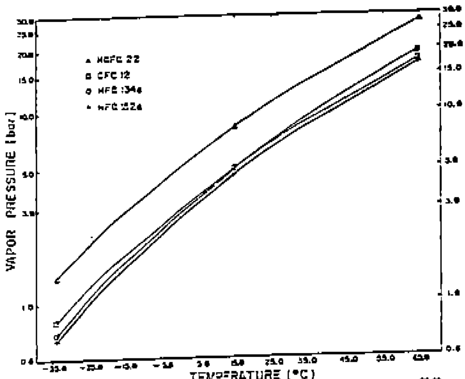


FIGURE 3 - Vapor pressure curve of the refrigerants as a function of the temperature. The pressures are represented on a logarithmic scale.

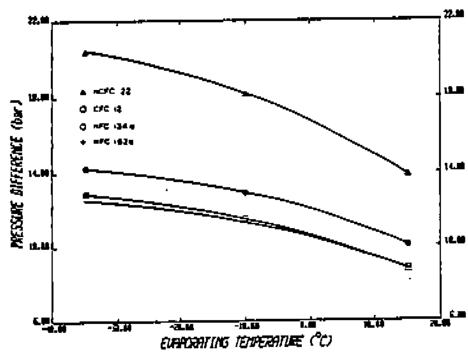


FIGURE 4 - Pressure difference between compressor suction and discharge at 55° C of condensing temperature.

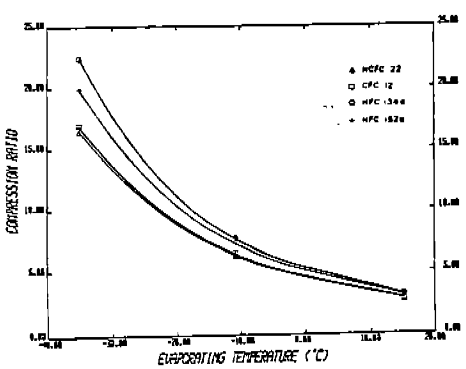
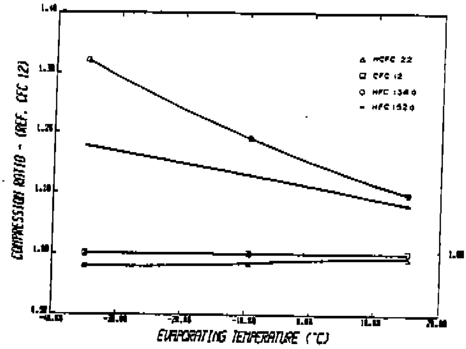


FIGURE 5 - Compression ratio - condensing pressure divided by evaporating pressure - considering 55°C of condensing temperature.

FIGURE 6 - Compression ratio to different refrigerants relative to the CFC 12 (CFC 12 is used as reference over the evaporating temperature range).



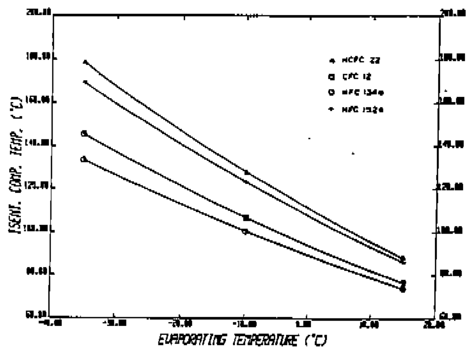
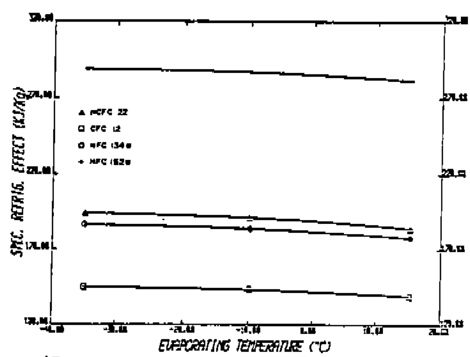


FIGURE 7 - Final isentropic compression temperature considering 55° C condensing temperature, and 32°C initial compression vapor temperature.

FIGURE 8 - Specific refrigerating effect considering 32°C of subcooling and superheating temperatures.



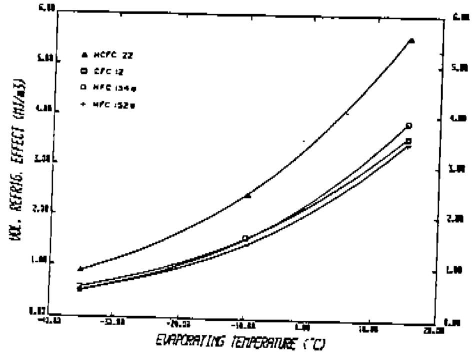
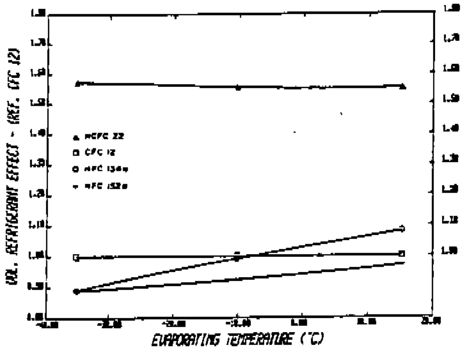


FIGURE 9 - Volumic refrigerating effect to 32° C of subcooling and superheating temperatures.

FIGURE 10 - Volumic refrigerating effect to different refrigerants relative to the CFC 12 (CFC 12 is used as reference over the evaporating temperature range).



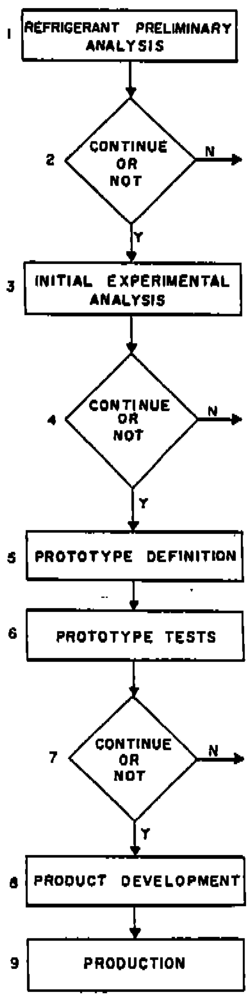


FIGURE 11 - Block diagram to the compressor development program applicable to new refrigerants.