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# OVERVIEW OF CFC REPLACEMENT ISSUES FOR HOUSEHOLD REFRIGERATION


Edward A. Vineyard
Oak Ridge National Laboratory

Lindsey Roke
Fisher and Paykel

Fred Hallett
Frigidaire, Washington, DC



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# OVERVIEW OF CFC REPLACEMENT ISSUES FOR HOUSEHOLD REFRIGERATION

**Ed Vincyard** **Lindscy Roke** **Fred Hallett**

## ABSTRACT

In 1974, the famous ozone depletion theory of Rowland and Molina claimed that chlorofluorocarbons (CFCs) diffuse into the stratosphere where they are broken down by photolysis to release chlorine atoms that catalytically destroy ozone. Although the understanding of the science is still imperfect, there is little doubt that CFCs play a major role in the Antarctic ozone hole phenomenon and the decline in ozone observed in the rest of the world. Another issue that has become increasingly important is the potential of CFCs to change the earth's temperature and to modify the climate. While the main impact in global warming is made by increased concentrations of carbon dioxide, CFCs and other trace gases also contribute to this effect. In an effort to respond to the global environmental threat, a CFC protocol was adopted during a diplomatic conference in Montreal. This document, known as the *Montreal Protocol*, was ratified in 1988 and put into effect on January 1, 1989.

In accordance with Article 6 of the *Montreal Protocol*, the countries that signed the agreement shall periodically assess the control measures provided for in the *Protocol*. As part of that assessment process, household refrigeration was investigated to determine the status of CFC-12 replacements. The conclusion was that much progress has been made towards finding a suitable replacement. Compressors designed for HFC-134a have efficiences comparable to those for CFC-12 and acceptable reliability tests have been obtained with ester lubricants. In addition, other replacements such as R-152a and refrigerant mixtures exist, but will require more study. Cycle options, such as the Stirling cycle, may be viable, but are further out in the future. The impact of new refrigerants is expected to result in elimination of CFC-12 consumption in developed countries by 1997 and in developing countries by 2005.

## INTRODUCTION

Domestic refrigeration, with a worldwide market of approximately 56 million annual sales, is an important end-user of CFCs due to the service it provides for food preservation. The vapor-compression cycle, which is used in the majority of units, uses CFC-12 as its working fluid. The fact that CFC-12 has been around for such a long time has allowed development of high-efficiency compressors and refrigeration system components.

Studies show that the average refrigerator will be used by the original owner for 10 to 15 years and will continue to give satisfactory service for a considerably longer period of time, up to 30 years in some instances. This kind of reliability has led consumers to expect a 15-to-20 year life for the hermetic unit. Over that time period an average compressor must operate anywhere from 60,000 to 90,000 hours without failure. To protect the consumer against the cost of premature failure, most manufacturers provide a full or partial refrigeration system warranty for up to five years [ASH88].

The efficient use of energy has become more important as larger storage capacities and more auxiliary devices, coupled with rising energy costs, have driven the cost of operation upward. In some countries, energy performance standards are mandating that energy consumption be drastically reduced within a short time period. Thus, the additional requirement of replacing CFC-12 has become a demanding exercise for manufacturers.

## REPLACEMENTS—NEW EQUIPMENT

### HFC-134a

HFC-134a, one of the first refrigerants tested as an alternative for refrigerator-freezers, is likely to be the leading candidate to replace CFC-12. Commercial supplies were available in early 1991. Selection of this chemical as the primary replacement for CFC-12 has been based mainly on demands from the automotive air-conditioning sector for a substitute with pressure levels and thermodynamic properties comparable to those of CFC-12.

Initial test results with HFC-134a were not very encouraging because energy consumption was much higher than with CFC-12 and because accelerated life tests revealed problems with high failure rates for some of the lubricants. In performance tests with HFC-134a, results for a drop-in replacement with no modifications to the system showed the energy penalty to be from 8 to 15%. More recent tests with systems designed for HFC-134a show results from 1% less energy consumption to a 7% energy penalty [Fis91]. The issue left to be resolved is the long-term reliability. The latest information from compressor manufacturers is that ester-based lubricants are the most promising candidates.

### HFC-152a

HFC-152a is one the best alternative refrigerants if one considers only ozone depletion potential (ODP) and theoretical energy savings. Additionally, the lubricant of choice, an alkylbenzene with a viscosity of 150 SUS, is commercially available at approximately the same cost as present lubricants used with CFC-12. However, few life tests have been performed, and energy consumption in units is somewhat higher than would be expected theoretically. HFC-152a has been shown to use from 4% less energy to 3% greater energy than CFC-12 in energy consumption tests-the best results among the alternatives [Fis91].

### Hydrocarbons

While the hydrocarbon propane is an established refrigerant with operating characteristics not too dissimilar from those of CFC-12, it is not seriously considered for domestic application because of its lower efficiency and flammability. In comparison with HFC-152a, propane has a much higher heat of combustion. However, it has a much lower greenhouse warming potential and is less expensive and more readily available than HFC-152a. Both are non-toxic and have zero ODP. A recent theoretical analysis has shown that propane is less efficient than HFC-152a but more efficient than HFC-134a [McL91].

Another hydrocarbon, cyclopropane, is regarded as a remote option because of the following shortcomings:

- It is not presently produced in large quantities.
- It is flammable.
- There are concerns about its stability.
- No work has been performed on lubricants and compressor reliability.

Sax 1989 lists cyclopropane in the section "Toxic and Hazards Review" as having mutagenic data and says that high concentrations are narcotic. Information is also given on flammability, but no overall hazard rating is given because of insufficient data [Sax89].

Theoretical studies have shown that cyclopropane could yield a 5% efficiency improvement over CFC-12. It is unclear, however, whether the studies were done with baseline models or more realistic simulations.

**HFC-134**

HFC-134, an isomer of HFC-134a, has a capacity at refrigerator operating conditions that is 76% that of CFC-12; therefore, it requires a much larger compressor to achieve the same run times. Chemical suppliers have indicated that HFC-134 is more difficult to synthesize than HFC-134a, so it would cost more to manufacture [Biv90]. In addition, HFC-134 is not presently included in the Program for Alternative Fluorocarbon Toxicity (PAFT) testing to determine long-term toxicological effects of new chemical compounds. Since these tests require several years to complete, HFC-134 would not be available for commercial use until the late 1990s even if PAFT tests began immediately.

In a single test conducted at ORNL, results of that HFC-134 had an energy consumption 6% higher than that of CFC-12, roughly equivalent to results of a similar test performed at ORNL with HFC-134a. The test was performed with an ester-based lubricant with a viscosity of 90 SUS [Vin91].

**Nonazeotropic Refrigerant Mixtures**

Nonazeotropic refrigerant mixtures (NARMs) have been proposed as alternative refrigerants that can provide more acceptable environmental consequences and, potentially, decreased energy consumption in domestic refrigerators. During evaporation or condensation of NARMs at constant pressures, the saturation temperature changes due to differences in the volatility of the component fluids. The temperature difference between the "dew point" and the "bubble point" of a NARM at any specified pressure is referred to as the refrigerant's "temperature glide." For domestic refrigeration, it is conceivable that a mixture could be chosen with a glide that would accommodate the temperature requirements for both the freezer and fresh food compartments. In order to fulfill the maximum potential for NARMs, the refrigeration circuit must be configured in the manner prescribed by Lorenz and Meutzner where two evaporators and intercoolers are used to provide heat transfer in the fresh food and freezer compartments. In simulation studies for a variety of fluids, efficiency gains of 6 to 26% have been predicted [San91].

One normally thinks of binary mixtures when NARMs are mentioned. However, another class of NARMS, ternaries, are an interesting alternative refrigerant since they offer the possibility of mixing three components together to match the desired boiling point and capacity of CFC-12. This procedure allows minimal changes in the system design that save time and money in design costs and retooling. In addition, the recommended lubricant for the ternary is alkylbenzene, a low-cost commercially available lubricant. Test results for the ternary range from 1% lower to 6% higher energy consumption with a mixture of HCFC-22 (36%), HCFC-152a (24%), and HCFC-124 (40%) [Fis91]. Other blends, some with zero ODP, are being considered.

## ALTERNATIVE TECHNOLOGIES

Stirling cycle refrigeration is a next-generation technology that is frequently mentioned as an alternative to the conventional vapor compression cycle for domestic refrigeration. Although the Stirling cycle is about 15% less efficient than the vapor compression at its current state of development, it is conceivable that advanced systems could be developed that exceed the present efficiency of vapor compression [Fis91]. A Stirling cycle would require no fluorocarbons in the refrigeration system, an attribute that might make it more attractive should problems arise with some of the alternative refrigerants. There are, however, several problems that must be overcome, the main one being system reliability. This is a major hurdle since present compressors are expected to last up to 90,000 hours. Presently, no Stirling engine has lasted anywhere near this long.

Absorption cycle refrigeration is a viable alternative to compression systems in domestic refrigeration since consumer products based on the absorption principle are already available in Europe. Absorption refrigeration relies on mixtures, such as ammonia-water-hydrogen or lithium-bromide-water, as the working fluids and can use either an electric heater or combustion (using natural gas, LPG, or kerosene) as the energy source instead of an electrically driven compressor. Small absorption refrigerators with similar cabinet load characteristics consume approximately twice the site energy of electrically driven compression refrigerators. The primary energy consumption of the absorption unit could be less than that of vapor-compression refrigerators if the absorption units have small freezers and are heated with high-efficiency natural gas burners. Similar reductions in primary energy consumption for sizes such as those common to North America may not be possible.

## REPLACEMENTS—RETROFITS

### Ternary Blend

The ternary HCFC-22/HFC-152a/HCFC-124 was initially mentioned as a service refrigerant. At present, however, activity in this market seems to have subsided, since the ternary requires an alkylbenzene lubricant. In some countries, though, such as Australasia (Australia/New Zealand), the ternary is still a possibility since most units are brought back to the shop for repair, where changing the oil, if required, is a simple process.

### HFC-134a

Field tests using HFC-134a and ester lubricants to service both automotive and larger commercial CFC-12 open-drive and semi-hermetic systems are giving encouraging results. However, little work is being done on servicing small hermetic-compressor capillary systems. Such systems have additional problems to be addressed, e.g., the need to ensure that no traces of paraffinic compounds remain that might block capillaries and the desirability of lengthening the capillary. If a method of flushing out CFC-12 systems and recharging them with HFC-134a is developed, it is probable that a compressor change will be required. Work is progressing on an oil for use in hermetic systems, and the situation is likely to become clearer by late 1992.

## FORECAST OF USAGE

Annual worldwide usage of CFC-12 for domestic refrigeration for 1990, shown in Tables 1 and 2, was determined from information gathered from several sources, such as the Association of Home Appliance Manufacturers, the European Community Association of Appliance Manufacturers, and private communication with manufacturers. The forecasts for the period 1995-2005 are based on an annual production growth rate of refrigerating capacity (arising from both more units and bigger cabinets) of 15% for developing countries (DCs) and 7% for developed (other) countries.

### CFCs

Undoubtedly, many countries, both developed and developing, will phase out the use of CFC-12 in domestic refrigeration faster than the *Protocol* requires. The rate of transition is hard to determine, however. Thus, the data for 1995 in Tables 1 and 2 have a larger degree of error than the data for 2000. The assumptions that were used to generate the tables are as follows: 75% of developing country production and 15% of developed country production will be using CFC-12 in 1995; by 1997, 50% of DC production will still be using CFC-12 while all other production will be CFC-free; by 2000, DC production with CFC-12 will be down to 10%; by 2005, there will be no CFC-12 in production. It was also assumed that any servicing with CFC-12 is insignificant.

### HCFCs

It is estimated that only 3% of domestic refrigerators have their systems serviced during their lifetimes. Thus, even if the HCFC-22/HFC-152a/HCFC-124 blend is widely used for servicing, HCFC use will peak at no more than 2% of the annual refrigerant usage. An additional 1% has been allowed for use of any HCFCs in blend applications or as straight refrigerants in new products.

### HFCs

Because the density of HFC-134a is about 10% lower than that of CFC-12, total HFC consumption will decrease by this amount over what it normally would be with CFC-12 refrigerator production. In addition, higher prices of the new refrigerants as well as environmental considerations are likely to result in increased recycling efforts. A trend that is counter to the aforementioned effects is larger, more efficient refrigerators with larger heat exchangers and refrigerant charges.

TABLE 1 Estimated refrigerant usage (metric tons) by years 1990-1997 and country type

| Ref. Type | 1990 | | | 1995 | | | 1997 | | |
|---|---|---|---|---|---|---|---|---|---|
| | DC | Other | Total | DC | Other | Total | DC | Other | Total |
| CFCs | 2200 | 6884 | 9084 | 3320 | 1450 | 4770 | 2930 | 0 | 2930 |
| HCFCs | 0 | 0 | 0 | 50 | 250 | 300 | 100 | 400 | 500 |
| HFCs | 0 | 0 | 0 | 1000 | 4920 | 5920 | 2630 | 9850 | 12480 |

TABLE 2 Estimated refrigerant usage (metric tons) by years 2000 - 2005 and country type

| Ref. Type | 2000 | | | 2005 | | |
|---|---|---|---|---|---|---|
| | DC | Other | Total | DC | Other | Total |
| CFCs | 890 | 0 | 890 | 0* | 0 | 0 |
| HCFCs | 150 | 150 | 300 | 50 | 50 | 100 |
| HFCs | 7200 | 12200 | 19400 | 16000 | 17000 | 33000 |

* Assumes DCs, such as China and India, will meet requirements earlier than *Protocol* requires.


SUMMARY

Significant progress has been made in the past two years toward finding a suitable replacement for CFC-12. The effort to redesign compressors for HFC-134a has resulted in units whose efficiency is comparable to that obtained with CFC-12. In addition, the effort in determining a suitable lubricant for HFC-134a has resulted in acceptable reliability tests for ester-based lubricants. In product tests, HFC-134a results compared with CFC-12 show energy consumption differences in the range of -1 to 7%.

Other options exist for replacing CFC-12 as the refrigerant working fluid in the refrigeration system. While HFC-134a appears to be the prime choice, other refrigerants might make more sense as replacements if higher energy efficiency can be realized. Of the other alternatives, HCFC-152a and the ternary HCFC-22/HFC-152a/HCFC-124 have received considerable attention. In performance tests, results for HCFC-152a energy consumption are in the range of 4% less to 3% greater energy, while results for the ternary are in the range of 1% less energy to 6% greater energy.

Refrigerant mixtures have also been considered in combination with alternative cycles, such as the Lorenz-Meutzner cycle. Presently, the theoretical energy savings for such cycles have not been attained in experimental testing. Other options, such as the Stirling cycle, may be viable, but are further out in the future.

CFC-12 consumption for domestic refrigeration is estimated at 9084 metric tons per year for 1990. Of that total, developing countries account for approximately 2200 metric tons, or 24%. Consumption is expected to be halved by 1995 and totally eliminated by 2005.

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