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THE CFC PROBLEM
REPORT OF THE SITUATION IN FRANCE AND EVOLUTION

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ABSTRACT

The paper deals with following points :

1. The refrigeration industry and CFCs in France

2. Subsequent development of the situation since the Montreal Protocol

3. Evolution of consumption

4. Position of the Authorities

5. Relations with the European Communities and comparison with the situation in the other countries of the C.E.E.

6. Position of Trade Associations and senior partners

7. Actual realizations

Conclusion :

The purpose of this description is to show how through massive cooperative action in a country with new-born ecological consciousness, it has been possible to attain to some spectacular and significant results, especially as regards CFC recycling process.

1. The Refrigeration & Air conditioning industry in France

Five main sectors are to be distinguished in this branch of the french industry.

Manufacturers : there are more than several hundred firms and it represents a global turnover of 3 10^9 US$.

Contractors (engineering & fitting)

Around 3.000 firms employing more than 10.000 persons

Distributors of components

Maintenance firms

Users (cold storage, retail...)

I shall draw your attention on a fact which is worth being noted : the main part of this activity concerns Refrigeration ; because of mild weather conditions in France less than 3 per cent cars are equiped with air-conditioning system.

CFC Producers

Only one company : ATOCHEM (a subsidiary of ELF AQUITAINE) is producing CFC, and around 15 firms have a distribution activity from 9 bottling plants, and more than 300 delivery points.

2. Subsequent development of the situation since the signature of the Montreal Protocol.

On the Authorities's instigations, several sensibilization meetings were organized. These meetings resulted in the signature of a Voluntary Agreement on february 7. 1989 between the Environment Ministry and Professionnal associations.

The text of this Agreement which is based on a strenghtened application of the Protocole spares the Refrigeration sector which is asked for a reduction of 20% in 1999 compared to the 1986 level.

We benefit in fact of the very important effort of reduction which is asked to the aerosol sector, on which all endeavours are focused. (this application represents more than 50 per cent of the CFC use in 1986).

However, hardly was it signed that this text of Agreement seemed already obsolete, just like the Montreal Protocole itself was.

At the European communities level (CEE) new negotiations are in progress in order to keep away from incoherencies (see & 5 hereunder).

3. Evolution of consumption

Repartition of french consumption in 1986
(by product)

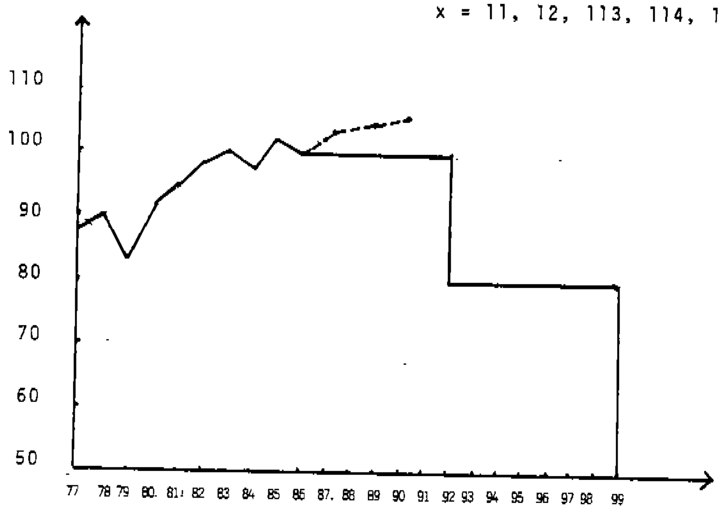
PRODUCT	WEIGHTED INDEX	ODP	WEIGHTED TOTAL AMOUNT
R 11	10	1	10
R 12	38	1	38
R 22	39	-	-
R502	13	0,3	4
others	ε	-	ε
TOTAL	100		52

Looking at this table it is clear that the effort of reduction bears on about 50 per cent of the total consumption.

Evolution of the weighted consumption from 1977 to 1999
(basis 100 in 1986)

$(\sum Rx \times ODPx)$

x = 11, 12, 113, 114, 115



The trend of the decade 77 to 8 9 (+1 to 2% per year) leads to a strenght of the reduction effort.

4. Position of the french Government

Up to this very day, the position of the Environment Ministry has not changed and complies with what was previously agreed on, i.e. a negotiation with a view to reach voluntary agreements at every level. (manufacturers, contractors, users).

But we are now faced with the fact that this position may interfere with the negotiations presently running at the C.E.E. level.

5. Relations with the European Communities and comparison with the situation in the other countries of the C.E.E.

Deep divergences between the different countries of the Community can be noticed and among them three great tendancies are to be distinguished.

5.1 Countries having adopted a contractual policy of agreements.

FRANCE

Voluntary Agreement of Feb. 7th 1989. Objective = - 20% by 1999 provided that there will be a recognition of professional qualification, adequate professional training of operators and recovery of refrigerants.

BELGIUM

Declaration of Intention of Jan. 1st 1989.
Objectives : - 25% by 1991 -50% by 1993 - 100% by 1995.
Provided that suitable alternatives will be available, certification schemes are to be developed to ensure competence in the application and handling of CFC in the refrigeration industry and that disposables will be prohibited.

As far as United Kingdom, The Netherlands and Switzerland are concerned, more informal means of achievement have been chosen.

5.2 Countries having chosen statutory authority

SWEDEN (which is not member state of the CEE)

Ordinance regarding CFC & Halon of june 1988, which prohibits the use of CFC in refrigeration from the 1st of January 1995forward and specifies that any person who has to handle CFC should be granted a permit from the National Environment Protection Board.

DENMARK

Action Plan for reduction of CFC.
- 50% in 1995
- 100% in 1999
- charge of 30 D. Kr./Kg of CFCs (6 US$) from january 1st 1989.

GERMAN FEDERAL REPUBLIC

Draft bill prohibiting the use of CFC as soon as 1992, together with limitation of R22 and no more production of CFC in 1995.

5.3 Countries which have not yet taken any measure

ITALY, SPAIN, PORTUGAL

6. Position of Trade Associations and senior partners

Facing this diversity or even incoherence the two main professional associations in Europe - CECOMAF (manufacturers) and AREA (contractors and distributors) - have asked the European Commission to act.

The result is a very ambitious text (Voluntary Agreement - Annexe I) which plans the following :

- 25% by the end of 1991
- 50% by the end of 1993

Our concern now is to ensure that every partner state strictly performs the achievement of the elaborated recommendations.

7. An actual case of realization - Recovery in France

Recovering CFCs is an ecological requirement as expressed in the Montreal Protocole, but also an economic necessity : it will indeed enable the industry to keep its R 12 filled refrigeration systems running on when production has stopped.

In France, since the 1st of July 1989, an easy way of collecting used refrigerants has been organized by the distributors ; it is financed through a 1 franc per kilo surplus on the sales price of the refrigerants . (R 22 is not concerned).

Up to now, the result is rather successful. But there is no use denying that significant hindrances exist : technical, economic and mainly psychological ones.

To improve this situation, recovery must no longer be considered as a constraint but as an opportunity for the refrigeration industry : both a service to the customers and a factor of qualification for the firms.

But to promote this change of mentality, it will be perhaps necessary that the governments take a further step towards a legislation.

Data on the CFC recovery	Quantity of CFC recovered (tons)	total market
1988	84 T	6.500 T
1989	139 T	

ALTERNATIVE, ENVIRONMENTALLY ACCEPTABLE REFRIGERATING CYCLES: A SOLUTION FOR THE CFC ISSUE?

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ABSTRACT

Unconventional, alternative refrigerating cycles without CFC's may contribute to the solution of the CFC issue.
The perspective of five alternatives for the conventional vapour compression cycle has been determined, compared to the conventional vapour compression cycle. For the determination of the perspective, CFC reduction potential and energy savings potential are the main aspects, related to the Dutch situation.
In general, the perspective will be more promising when the use of HCFC 22 will be restricted.
The main results for each alternative are given below.

- The natural gas heated absorption household refrigerator has a moderate CFC reduction potential. The energy efficiency may be competitive (by means of heat recovery or process optimization), Connection with the natural gas distribution system reduces the flexibility of the appliance.
- 'Natural refrigeration', combined with cold storage hardly contributes to CFC reduction. In particular cases the system will lead to considerable energy savings.
- The Joule-Brayton cycle, particularly the 'Edwards Cycle' is still in an early stage of development; it is necessary to undertake a feasibility study before an assessment of the 'Edwards Cycle' can be made.
  The Open Air Cycle, also based on the Joule-Brayton cycle, has a considerable CFC reduction potential. The energy saving potential mainly depends on the efficiency of the main components; with modern machines designed for this application, this concept may be energy-competitive.
- A Stirling cycle transport refrigeration system has a small CFC reduction potential. The cycle may also be used for several other applications. In that case the application and CFC reduction potentials are considerable. The energy saving potential is questionable.
- The compression-absorption cycle has a considerable CFC reduction potential. In some applications, notable energy savings can be achieved.

1. INTRODUCTION

Due to the CFC issue, the Refrigeration Industries are confronted with limitations of the use of CFC 11, 12, 114, 115 and probably long term restrictions of HCFC 22 [1], [2]. Unconventional, alternative refrigeration cycles without CFC's may contribute to the solution of this problem.
At the moment, almost every refrigeration system is based on the vapour compression cycle. Several other principles have been proposed and applied in the past with more or less success, but the specific advantages of the vapour compression cycle are obvious. However, due to the CFC issue, the perspective of some alternatives has changed. The fact is that in many applications it is difficult to find alternative, environmentally safe refrigerants to be used in conventional vapour compression systems; moreover, many alternative refrigerants will lead to an increase of the energy consumption.
In this context, the application of alternatives for the conventional vapour compression system is an interesting option.

This paper gives a review of the results of a study, funded by the Dutch Ministry of Environmental Affairs, concerning the perspective of alternative, environmentally acceptable, refrigerating cycles.

In this study, 'environmentally acceptable' means that no CFC's or HCFC's are used in the refrigeration system, and that the energy consumption does not increase, compared to the conventional system. The (H)CFC's in isolation foams are not considered.

The perspective of the alternative cycles is related to the following aspects:

- technical feasibility;
- application potential;
- CFC reduction potential;
- energy saving potential;
- remaining environmental effects;
- required Research & Development;
- economy;
- time needed for introduction;
- chances and prospects for the Dutch industry.

The perspective is considered for the Dutch situation. The CFC reduction and energy saving potentials are related to the application potential in The Netherlands.

2. PERSPECTIVE OF FIVE ALTERNATIVE REFRIGERATING CYCLES

2.1 Choice of the cycles considered

Based on a detailed literature survey, five alternatives for the conventional vapour compression cycle have been selected. They are discussed in the following sections. The main selection criterion was the foreseen technical feasibility (no "paper" concepts). Of course, this selection is not complete. Nevertheless, the selection provides in our opinion a general insight in the perspective of alternative, environmentally acceptable refrigerating cycles.

2.2 Absorption household refrigerator

The natural gas heated absorption household refrigerator is a commercially available appliance, mainly used in Europe for hotel and camping applications [3]. Normally, the refrigerant used in this type of refrigerator is ammonia; the absorbent is water. In some appliances, a small amount of hydrogen is added.
The appliance is well suited for combination with a heat recovery system for heating of the domestic hot water supply. The refrigerator can deliver a substantial part of the required heat for the hot water need of a family dwelling. However, for the current energy costs in The Netherlands, the Simple Pay Out Time (SPOT) for the heat recovery system is 7 to 9 years [4].
The flexibility of the appliance is less due to the connection with a natural gas distribution system and, in case of heat recovery, due to the connection with the hot water system.
The application potential is very large. The related CFC reduction potential is moderate. The energy saving potential depends largely on the efficiency of the absorption system and the combination with heat recovery. Based on primary energy, the energy consumption of the present absorption household refrigerator, without heat recovery, is more or less the same as the consumption of the conventional refrigerator. Besides, it seems possible to improve the energy efficiency of the present absorption refrigerator significantly.
The present absorption household refrigerators are somewhat more expensive than the vapour compression types, probably due to the relatively small production quantities. R&D has to be pointed at cost reduction, energy efficiency and augmentation of flexibility.
The absorption technique can also be used for many other applications (industrial, commercial, air conditioning). These applications are analyzed in a separate study; however, results are not yet available. We have the preliminary impression that, under certain conditions, some applications of the absorption cycle show an interesting perspective.

2.3 'Natural refrigeration', combined with cold storage

The production of 'artificial snow' in combination with storage of the produced snow, may reduce the need of mechanical refrigeration equipment and can thus be considered as an alternative refrigeration system, although it is not really a new 'cycle'.
Several publications provide information about this kind of systems [5], [6]. For the production of snow, a standard snow machine is used (normally used in ski areas). For snow production, the ambient temperature has to drop under -1 °C.
The produced snow is stored in a hole, covered by an isolated shell, e.g. a covering or tent; the melted snow delivers the cold water (0 to 6 °C) for comfort or industrial process cooling.
The application is restricted due to the required space for the storage system (5 to 10 m^2 per kW duty) and the noise produced by the snow machine.
For the Dutch situation and climate, the minimum plant size is about 100 kW refrigerating capacity.
Due to the above mentioned restrictions, the application potential is small. The CFC reduction potential is small due to the small application potential and the fact that in most cases a (partial) back-up system is needed.
However, in particular cases the system will lead to considerable energy savings.
R&D has to be pointed at system optimization and component attunement.

2.4 Joule-Brayton cycle

Since the beginning of this century, refrigerating systems according to this cycle are built. At present, this cycle is only used in a commercial scale for applications at very low temperatures.
The main differences between the Joule-Brayton cycle and the vapour compression cycle are:
- the refrigerant remains in the vapour phase instead of evaporation and condensation;
- expansion of the vapour takes place in a turbine instead of a throttling device;
- the ideal cycle has a 100 % Carnot efficiency.

Two concepts, based on this cycle, have been studied.

'Edwards Cycle'

In 1977, Edwards reported an application of a modified Joule-Brayton cycle (the so called 'Edwards Cycle') [7], [8]. In this cycle, the original cycle is combined with a evaporating and condensing component in a binary refrigerant mixture. (i.e. air and water). Theoretically, this modified cycle will be more efficient than the original one. Edwards used a combined compressor/expander based on the constrained rotary vane principle. In the seventies, a prototype was used for mobile air conditioning.
The application potential for mobile air conditioning in The Netherlands is very small; nevertheless, this cycle may be used for several other applications.
An analysis of the information obtained showed that there is still talk of an early stage of development; it is necessary to undertake a feasibility study before an assessment of the 'Edwards Cycle' can be made. At the moment, the main interest of Edwards is related to rotary vane compressors for low density refrigerants in a conventional vapour compression cycle.

Open Air Cycle

Another concept based on the Joule-Brayton cycle is the Open Air Cycle, proposed by the Dutch firm Grenco. This concept consists of a externally driven compressor, a compressor/expander combination (without external drive) and a regenerative heat exchanger. Refrigerating plants based on this concept are already used in the USSR for several years.
The main advantages are:
- absence of evaporators (air coolers) and condensers;
- absence of cooler (de)frosting;
- no fans needed for air circulation;
- good capacity control characteristics.

These advantages sound very interesting although it will take much R&D effort to realise practical, energy efficient applications.

The application potential as well as the CFC reduction potential is considerable. The energy saving potential mainly depends on the efficiency of the compressor and expander; with modern machines designed for this application, this concept may be competitive.
In our opinion, a multinational (European Community) R&D project is preferable.

2.5 Stirling cycle

The Stirling machine is used since many years for cryogenic applications (f.e. liquifying of nitrogen).
Originally, the Stirling cycle was used as a heat-driven engine; afterwards, the reverse cycle is used for cooling purposes. The refrigerant (in most cases helium or hydrogen) is pulsating between two pistons moving in one or two cylinders and passes a regenerative heat exchanger. The ideal cycle has a 100 % Carnot efficiency; the real Stirling cycle normally reaches a 17 to 25 % Carnot efficiency. For cryogenic applications, this is a competitive value; for applications in the range of -40 to +10 °C this value is in many cases less than the efficiency of vapour compression cycles. Recently, a transport refrigeration system has been developed, based on this system [9]. This Yody* system is promoted as a compact, lightweight, hermetically sealed system with high reliability at low maintenance costs. The Stirling cooler uses helium as refrigerant and is combined with a cold distribution system based on a heat pipe technique. Half the input power required by a conventional system is claimed; however, the Carnot efficiency of a conventional transport refrigeration system is rather low, compared to other refrigeration systems.
The application potential as well as the CFC reduction potential is small. The energy saving potential depends largely on the efficiency of the cryocooler; the design goal is to achieve 25 to 28 % Carnot efficiency, which is competitive to conventional transport refrigeration systems.
The Stirling refrigerator may also be used for several other applications. In many cases, the Carnot efficiency of conventional vapour compression cycles is higher than the above mentioned design goal; thus the energy saving potential is questionable. Based on the available technical information, the Yody* system is hard to compare with conventional systems, particularly due to the combination with the unconventional cold distribution system. Hence, a detailed (experimental) investigation of the Yody* prototype is recommended.

2.6 Compression-absorption cycle

In the compression-absorption cycle, the benefits of the compression and the absorption principle may be combined. Many construction variants are proposed. In the simplest construction, the cycle consists of a conventional vapour compression cycle, using a non azeotropic refrigerant mixture (NARM). A complex construction consists of a vapour compression cycle, combined with a liquid cycle, using a refrigerant and an absorbent [10], [11].
The application potential, as well as the CFC reduction potential is considerable. In some applications, notable energy savings, compared to the conventional vapour cycle, can be achieved (10 to 50 %). Maximum savings may only occur when considerable temperature gradients on the secondary side of a counter flow evaporator and condenser can be realised. In general, standard or slightly adapted components can be used. R&D has to be pointed at the choice of refrigerants and the selection and adaptation of components.

3. DISCUSSION AND CONCLUSIONS

3.1 Mutual comparison of alternative cycles

The five alternative cycles, described in the previous chapter, can be compared to each other. The application potentials, CFC reduction potentials, energy saving potentials and required R&D are given in table I.

3.2 Perspective in relation to HCFC restrictions

The perspective of alternative cycles is strongly related to the future restrictions of HCFC's, particularly HCFC 22.
In case of unlimited use of HCFC 22, there will be no strong need for alternative cycles, because of the fact that, for most of the applications, alternative refrigerants will be available. In case of restriction of HCFC 22, there won't be any long term alternative refrigerant for many applications; alternative cycles may then contribute significantly to the solution of the problem.

3.3 Summary of conclusions per alternative cycle

Absorption household refrigerator
The application potential is large, the CFC reduction potential is moderate. The energy saving potential depends largely on the efficiency of the absorption system and the combination with heat recovery. R&D has to be pointed at cost reduction, energy efficiency and augmentation of flexibility.

'Natural refrigeration', combined with cold storage
The application potential and the CFC reduction potential are small. In particular cases the system will lead to considerable energy savings. R&D has to be pointed at system optimization and component attunement.

Joule-Brayton cycle
- 'Edwards Cycle'
An analysis of the information obtained showed that there is still talk of an early stage of development; it is necessary to undertake a feasibility study before an assessment of the 'Edwards Cycle' can be made.
- Open Air Cycle
The application potential as well as the CFC reduction potential is considerable. The energy saving potential mainly depends on the efficiency of the compressor and expander; with modern machines designed for this application, this concept may be competitive. A multinational (European Community) R&D project is preferable.

Stirling cycle
The application potential as well as the CFC reduction potential is small in case of transport refrigeration. The cycle may also be used for several other applications. In that case the application and CFC reduction potentials are considerable. The energy saving potential depends largely on the efficiency of the Stirling machine. The design goal is to achieve 25 to 28 % Carnot efficiency; thus the energy saving potential is questionable. Experimental investigation of the Yody™ prototype is recommended.

Compression-absorption cycle
The application potential, as well as the CFC reduction potential is considerable. In some applications, notable energy savings, compared to the conventional vapour cycle, can be achieved (10 to 50 %). R&D has to be pointed at the choice of refrigerants and the selection and adaptation of components.

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Table I: application potentials, CFC reduction potentials, energy saving potentials and required R&D of five alternative cycles*).

Cycles	1a	1b	2	3a	3b	4a	4b	5
Application:								
- domestic	+						+?	▪
- commercial		+?		+?	+		+?	▪
- transport				+?	+	+		▪
- industrial		+?	-		+			▪
- air cond.		+?	-	+	+		+?	▪
Bulk CFC reduction	▪	+?	-	-?	+	-	+?	+
Bulk Energy saving	+?	▪?	▪	-?	+?	-	+?	▪
Required R&D	•	♦	•	♦	♦	•	♦	♦

+: large ▪: moderate -: small ?: questionable
♦: much R&D •: little R&D

Cycles:
1: Absorption cycle 1a: household; 1b: other applications
2: 'Natural refrigeration'
3: Joule-Brayton cycle 3a: Edwards Cycle; 3b: Open Air Cycle
4: Stirling cycle 4a: Yody transport; 4b: other applications
5: Compression-absorption cycle

*) Related to the Dutch bulk CFC consumption and energy consumption for refrigeration purposes.