# CHLOROFLUOROCARBON REFRIGERANTS AND THE ENVIRONMENT: NIGERIA, WHICH WAY FORWARD?

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## 1.0 ABSTRACT

This paper highlights the effects of impending changes on the refrigeration and other related industries, caused by the continued use of some offensive refrigerants commonly found in Nigeria. Recent ozone measurements analysis yielded an unexpected seasonal depletion in the atmosphere. The release into the atmosphere of some chlorofluorocarbon (CFCs) refrigerants, notably R11, R12, R113, R114 and R115 has been found to contribute to this ozone depletion. The Montreal Protocol agreed upon in 1987, a reduction of 50% of 1986 level of consumption before the end of this century. This ultimately leads to the search for new refrigerants to replace the offensive ones.

## 2.0 INTRODUCTION

In order to effectively replace the offensive refrigerants, it is essential that there be full knowledge of the properties of these new refrigerants and the methods of their classification. It must be borne in mind also that the need for the replacement of these refrigerants emanates from their global effect on ozone layer depletion in the atmosphere rather than their non-performance in the refrigeration and air conditioning systems.

### 2.1 Desirable Properties of a Refrigerant

An ideal refrigerant must satisfy the following requirements (1,2):

(i) Chemical Stability and Innertness

Should be non-corrosive and chemically stable through the range of operating conditions. Stability could, however, be a double-edged sword; once emitted to the atmosphere, a refrigerant should not be so stable that it persists indefinitely. The ideal refrigerant, therefore, would be totally stable in use but decompose within a few years in the atmosphere due to conditions not present in the sealed system.

(ii) Nontoxicity, Non-irritability, Non-flammability and Non-atmospheric Degradation

Other desirable properties of a refrigerant relating to health and safety are non-toxicity, non-irritability and non-flamability to which could be added, the environmental requirement that the refrigerant should not contribute to ozone depletion, low level smog formation or greenhouse warming.

(iii) Thermal Properties (Thermodynamic and Transport)

These properties determine the performance of a refrigeration system. These include:

(a) High heat-transfer characteristics: A broad statement involving properties such as density, specific heat, thermal conductivity and viscocity. High heat transfer coefficients reduce the surface area required in heat exchanges.

(b) Relatively high critical temperature: The critical temperature of refrigerant needs to be much higher than the condensing temperature to prevent unduely large power requirement. These two fundamental criteria account for all the desirable properties usually presented, such as positive evaporating pressures, moderately low condensing pressures and high latent heat of vaporisation.

(iv) Other Required Properties

The following more practical criteria are also desired for a suitable refrigerant:

- high oil solubility and high vapour dielectric strength are most important for hermetic compressors;
- freezing temperature, to be sufficiently low to prevent solidification of refrigerant at normal operating conditions.
- compatibility with common materials of construction.
- low cost of refrigerant, and,
- easy leak detection using a simple positive method.

2.2 Designation of Refrigerants

CFC is a family of chemical compounds derived from simple hydrocarbons (methane, ethane etc) by substitution of halogen atoms (chlorine, fluorine) for hydrogen. CFCs have been discovered as far back as the 1890s by a Belgian researcher, Dr. F. Swarts (3). However, the discovery was of little interest until 1928 when Thomas Midgley, a scientist at the Deko Laboratories of the General Motors Corporation signled them out for consideration as working fluids in refrigeration equipment produced by General Motors' Frigidaire Division. They have since then displaced most of the refrigerants before them because of their desirable properties notably, nontoxicity, non-flamability, miscibility with oils and chemical stability.

In designating the hydrocarbon and halocarbon refrigerants, the numbers assigned are arrived at thus:

(i) the first digit from the right is the number of flourine (F) atoms in the refrigerant.

(ii) the second digit from the right is one more than the number of hydrogen (H) atoms present.

(iii) the third digit from the right is one less than the number of carbon (C) atoms. The digit is often omitted when it is zero. Hence, ethane ($C_2H_6$) is R170 and dichlorodifluoromethane ($CCl_2F_2$) is R12. For the inorganic refrigerants, 700 is added to the molecular weight of the compound. Thus, Ammonia is R 717 and water is R 718. The CFC derivative of methane ($CH_4$) and ethane ($C_2H_6$) are shown in figures 2 and 3 respectively (4).

The Udoji award of 1974 avails several families to own refrigerators, freezers and air conditioners which use some of these offensive refrigerants. The advent of new refrigerants (for replacement purpose) may result in the modification of existing methods, equipment and processes. Hence in the following sections, the effects of CFCs on the environment and the effects of their restriction on the Automotive, Air Conditioning and on Commercial Refrigeration Equipment Manufacturing Industries are discussed.

3.0 Effects of CFCs On The Environment

Two important effects the release of some CFCs could have on the earth surface are:

(i) The ozone layer depletion, and

(ii) the greenhouse effect.

The ozone layer actually consists of ozone present at very low concentrations in the stratosphere between 11 and 45km in altitude, Fig. 1. Ozone, or $O_3$, is formed by the interaction of ultraviolet (UV) radiation from the sun with molecular oxygen ($O_2$). Harmful UV radiation is absorbed during this formation process and also directly by the $O_3$ once it is formed. Ozone is unstable and eventually will revert back to $O_2$. The ozone depleting effect is caused by the migration of very stable refrigerants of the CFC type to the upper atmosphere (stratosphere). It is generally accepted that in the stratosphere, the stable CFC refrigerants become involved in catalytic reactions which have the effect of breaking down ozone without first destroying the chlorine released from the CFCs. The most harmful CFCs have an active ozone destroying life in the stratosphere of over 100 years. Since ozone layer filters out harmful UV radiation which might otherwise reach the surface of the earth, its depletion could result in high concentration of UV radiation on the earth surface. This could result in damaging effects on people, plants and photo-plankton of the ocean. In addition, increase doses of UV light could cause malignantskin cancer in fair skinned people.

The greenhouse effect is caused by the absorption of long wave radiation from the earth's surface by CFCs, among other susbtances in the troposphere. Short wave radiation from the sun has most of its harmful components filtered out by the ozone layer. The rest of the short wave radiation heats the surface of the earth and the seas. These surfaces give off longer wave radiations which can be trapped by a variety of gases including CFCs which act like an insulating blanket. There is thus a tendency for global warming due to the polution which we have allowed to accumulate in the atmosphere. The ecological systems of the world are very finely dependent on temperature. Fractions of a degree change in average temperature can radically affect the distribution of crops and animals.

Fig. 4 shows the CFC family where besides carbon, hydrogen, chlorine or fluorine, the fields of toxicity, inflammability and chemical stability for a long atmospheric lifetime are shown. It can be seen here that the fully halogenated refrigerants have long atmospheric life which results in ozone depletion and the attendant greenhouse effect. The theories about these environmental effects, led to the Montreal Protocol that calls for a freeze in CFC 11, 12, 113, 114 and 115 at 1986 consumption levels beginning about July 1989. Reductions of 20% from 1986 levels of these same chemicals would be required by 1 July 1993 and reduction of 50% required by 1 July 1998. Halon - 1211, 1301 and 2402 would be frozen at 1986 consumption levels in 1992 or 3 years after entry into force. Table 1 shows the eight chemicals controlled by the Montreal Protocol subdivided into CFCs and halons (5).

Table 1: - Chemicals Covered by the Montreal Protocol (5)

| Group I | | Group II | |
|---|---|---|---|
| Chemical | Depletion Weight | Chemical | Depletion Weight |
| CFC 11 | 1.0 | Halon - 1211 | 3.0 |
| CFC 12 | 1.0 | Halon - 1301 | 10.0 |
| CFC 113 | 0.8 | Halon - 2402 | ----* |
| CFC 114 | 1.0 | | |
| CFC 115 | 0.6 | | |

*To be determined

All the refrigerants identified for restriction except R 113 are used to some extent in the application of concern to human comfort. R 113 is used mainly as a cleaning solvent by the electronics industry. Refigeration equipment, commercial shillers and automobile air conditioners use R 11, R 12 and R 114. R 115 is not normally used by itself as a refrigerant but it is a constituent of the azeotropic refrigerant R 502 which is used in commercial refrigeration equipment. Besides being used on its own, R 12 is also a constituent of R 500 which is used in chillers.

In general, all refrigeration systems tend to release CFCs at the same points: during manufacturing, including leak testing, reworking and shipping, during installation, during use, servicing and during product disposal. The released products go to the atmosphere and the fully halogenated ones with long atmospheric life contribute to the ozone layer depletion. This has necessitated the need to control the emission of these offensive refrigerants or even to replace them completely. Statt (6) in his analysis, concluded, that refrigeration, mobile air conditioning and foam insulation all contribute fairly evenly to the ozone depletion problem.

## 4.0 Effects of CFC Restriction on the Automotive Industry

R 12 is the refrigerant commonly used in vehicle air conditioners for charging new installations, making up for leakage from existing systems and replacing the entire charge in units vented during service or repairs. Consumption of R 12 in the U.S.A. for automotive air conditioners in 1986 is estimated at 40% of the national R 12 production whilst in Japan, R 12 consumption in mobile air conditioners is an estimated 25% of total national R 12 consumption (6). In Nigeria, even though cars are not manufactured here, an appreciable number of both imported and locally assembled cars have air conditioners which also use R 12, so a restriction of the use of R 12 in the developed countries will affect us appreciably.

The control of consumption of R 12 according to the Montreal Protocol may have different effects on the various industries in each country.

Appropriate steps will be taken towards lowering R 12 consumption by the automobile industries in the U.S.A. and Japan, where the demand for R 12 in mobile air conditioners is disproportionately high. The international vehicle market, together with a world-wide sales and service network will cause certain largely importing countries (like

Nigeria) to take similar steps although mobil air conditioners do not play a part as important as that in the U.S.A. and Japan. For instance, a 13.5kg can of R 12 which sold for about ₦500.00 in June 1991 costs about ₦1,800.00 in June 1992.

Kern and Walker (7) proposed some medium-term measures bothering on the introduction of service and repair precausions, and using alternative refrigerants. The service measures include: improved leak detecting methods; R 12 recovery in service and repair work and R 12 recovery at vehicle disposal. The air conditioning system measures include the improvement of equipment to give improved sealing effect such as hoses and compressor shaft seals. On alternative refrigerants the most promising new replacement of R 12 is R 134a. However, aside from some engineering problems, there are still some toxicologic questions to be answered.

## 5.0 Effects of CFC Restriction on Air Conditioning and Refrigeration Industry

In the U.S., the Environmental Protection Agency (EPA) for a guide in their proposed rule making, requested comments on four different approaches for regulating CFCs:

(i) A Production Quota System: Concerned with limiting the production of the covered chemicals to be in compliance with the Montreal Protocol.

(ii) Permit System: The EPA would assign or auction CFC permits to producers and/or users. However, administrative obstacles are likely to be encountered with this system which could encourage hoarding and major disruptions.

(iii) A Fee System: Users and producers to pay fees to the EPA for the rights to covered chemicals.

(iv) Engineering Controls: These could include specific design parameters for functional features within air conditioning and refrigeration equipment. This option could inhibit innovation of new product development and would not assure compliance with the Montreal Protocol.

The air conditioning and refrigeration industry generally regards the quota system as the most reasonable approach to be in compliance with the Montreal Protocol (8).

Of the restricted compounds, R 11 and R 12 will have the major impact due to their wide use in automotive air conditioning, domestic and commercial refrigeration and centrifugal chillers. Alternative refrigerants available in the short term include R 22, R 500, R 502 and certain blends but these are not suitable substitutes for all applications. R 134a and R 123 are environmentally acceptable substitutes which appear promising for new equipment but information on them is preliminary and they will not be commercially available for several years.

Creswick et al (9) suggested that alternative cycles need to be re-examined as back-up substitutes. For instance, absorption chillers could be substituted for centrifugal chillers in commercial space-conditioning applications.

## 6.0 Impact of CFC Restriction on Commercial Refrigeration Equipment Manufacturers

Of the CFCs identified for regulation, the following are the specific interest to the equipment manufacturers:

- R 11 used in insulation,
- R 12 used as a refrigerant,
- R 115 used with R 22 to make R 502.

Refrigerator Manufacturers Association in the U.S. enumerated the chief concerns of manufacturers as follows (10).

(i) performance of existing installations.
(ii) redesign of products currently in production.
(iii) design of new products.

Systems designed for R 12 will perform better on R 12. Changing the refrigerant to R 502, for example, may cause operating problems. For instance, substantial changes in components may be needed because of higher operating pressures and greater electrical system requirements. Because of the substantial quantities of R 12 and R 502 in existing installations, it is important that adequate amounts of R 12 and R 115 are available over the next few years for service purposes.

Products currently in production which will be affected by the CFC regulations are self-contained refrigerators. Many medium temperature models are designed for R 12 and with the condensing unit being an intergral part of the system, changing the system refrigerant to R 22 or R 502 may require a redesign for selection of matching component parts. Laboratory and field tests will also be necessary to insure satisfactory performance levels.

Alternative refrigerants to R 12 are under investigation. R 134a is proving to be a good substitute although more tests are still required to ascertain its toxicity level. The impact on manufacturers of substitute refrigerants will be considerable as design modifications will be needed.

## 7.0 Concluding Remarks and Recommendations

The CFCs identified for regulation according to the Montreal Protocol are R 11, R 12, R 113, R 114 and R 115. The most widely used in this country is R 12 followed by R 115 which is a constitute of R 502 used in commercial refrigeration equipment. R 22 is another refrigerant commonly used in this country but since it also contains chlorine, it has ozone depletion potential even though to a lesser extent than R 12 because it contains hydrogen. It is, however, widely accepted that chlorine and hydrogen containing fluid have a low environmental effect hence, they are not included in the Montreal Protocol.

The ozone depletion and greenhouse effects are global problems requiring global solutions. Consumer countries such as Nigeria should also cooperate to enforce the measures contained in the Montreal Protocol as measures taken by a few nations could have only a minor impact upon reducing total emission.

### 7.1 Recommendations:

Kuijpers (11) and Braswell (12) suggested some recommendations which are also valid here in addition to some others that are unique to the Nigerian situation alone.

(i) R 12 is a non-toxic, non-inflammable, odourless and chemically stable refrigerant with wide use for automobile air conditioning, household refrigerantors and freezers. It operates well in ambient temperatures between 10°C and 42°C and for internal temperatures between +10°C and -18°C. it is not an easy task finding a suitable alternative with similar all round favourable properties. Interested researchers should be encouraged through financial support by government to join the concerned countries in the search for alternative refrigerants.

(ii) Increased use of equipment using R 22 should be encouraged. R 22 is, however, relatively more expensive than R 12. The use of ammonia and hydrocarbon refrigerants for certain applications should also be further investigated.

(iii) Other halogenated alternatives are R 134a and R 123 for R 12 and R 11 respectively. R 11 is used as a blowing agent for polyurethane insulations which are not yet produced in this country. R 134a has similar properties to R 12 but tests to determine its toxicity have not been conclusive. When these alternatives are eventually accepted, their production in this country should be encouraged as the raw materials are locally available.

(iv) Most of the operators of the refrigeration and air conditioning industry in this country are not aware of the problems their careless handling of the CFC refrigerants are causing worldwide. There is therefore the need for public enlightenment to intimate them and the public at large on the consequences of ozone layer depletion and the greenhouse effects.

(v) Some measures aimed at recovery of the refrigerants at equipment disposals and during service and repair works should be introduced.

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