SOURCES OF HYDROCHLOROFLUOROCARBONS, HYDROFLUOROCARBONS AND FLUOROCARBONS AND THEIR POTENTIAL EMISSIONS DURING THE NEXT TWENTY FIVE YEARS

ARCHIE McCULLOCH
ICI Chemicals & Polymers Ltd., Runcorn, WA7 4QF, United Kingdom

Abstract. In common with CFCs, the classes of compounds in the title have wholly anthropogenic sources. CFCs are used for refrigeration, air-conditioning, foam blowing, solvent cleaning and propelling aerosols and, in each case, equipment has been designed to make the most efficient use of the properties of individual compounds. There is little scope for substitution, even between CFCs. The potential for replacement of these historic uses by substitute technologies - ammonia, hydrocarbons, carbon dioxide and HCFCs, HFCs and FCs - is examined. It is shown that the quantities required are influenced as much by improvements to containment as they are by the primary demands from society. Based on analysis of the historic data; the declared manufacturing capacities, and the anticipated effects of international controls, the potential production and emissions of the principal HCFCs and HFCs are calculated for the next twenty five years. While consumption of HCFCs will fall nearly to zero, it would appear that demand for HFC-134a could double, from approximately 150,000 to 300,000 tonnes/year between 1995 and 2020. Over the same timescale demand for HFC-32 could rise to 90,000 tonnes/year. The potential future emissions of other HCFCs, HFCs and FCs which are expected to be used less widely, or for which there is no current consumption base from which to make meaningful extrapolations, are also discussed.

1. Introduction

The assessment of potential effects of future emissions of any compound, natural or man-made, will depend on the quantities emitted. For predictions of the consumption of substitutes for CFCs we are fortunate to have a long term database for historic consumption (AFEAS 1993) which can be analysed to determine underlying market trends. This paper describes the results of such analyses and their application to those substitutes which now seem to be the most likely, viable successors of CFCs.

2. Substitution

The scope for substitution even between CFCs is very limited. Alternative compounds must match the properties needed to provide the specific effect desired and, additionally, should be toxicologically and environmentally acceptable in use. Alternative technologies, on the other hand, have no need to match the physical and chemical properties of CFCs (although they too should be toxicologically and environmentally acceptable) and it is expected that almost half of the demand will be taken up by chemicals other than fluorocarbons (GECR 1993).

In general, the models to describe substitution concentrate on the technical feasibility of replacements, with less importance being attached to the non-technical considerations: price and toxicology. Externalities, such as customer confidence in and perception of the final product, cannot be considered in any but the most subjective manner (Shapiro 1993). On the other hand, announcements of plant construction programmes, such as those in ECN (1993), give a clear indication of which alternatives are perceived to be viable. It would seem that the alternatives currently favoured globally are HCFCs 22, 141b and 142b and...
HFCs 134a and 32, with minor amounts of HCFC-123 and HFCs 125 and 143a (Verhille 1992; McCarthy 1993; ECN 1993). The minor compounds have properties which will militate against widespread deployment. HFCs 125 and 143a have atmospheric lifetimes which are comparable with those of the CFCs, giving rise to concerns about persistence in the environment. HFC-152a is flammable and HCFC-123 has adverse toxicological properties. As for HCFC-124, its physical properties do not readily suit it to refrigeration applications and none of the references cited above predicts a significant demand for this compound.

The substitutes for the principal uses of CFCs and the demands for the halocarbon alternatives in the next few years are summarised in Table I. While there are many technologies and, indeed, fluorocarbons which have been claimed to provide the effects shown, only those which are technically viable now, and hence may be expected to be commercially available in the near future, are considered.

3. CFCs as Demand Models

The long term data sets for CFC and HCFC demand in refrigeration, air-conditioning, foams, aerosols and solvent applications (AFEAS 1993) can be analysed to ascertain the underlying trends in demand for those effects. This is described below for the refrigeration and air-conditioning markets (areas 3 to 5 in Table I); in these areas, the fluorocarbons in most common use were CFC-12 and HCFC-22.

It is self-evident that demand for any product does not spring into being; it build-up over time. Eventually, the same product will be overtaken by one that is technologically superior. This has been quantified for chemicals as an 'S' curve, of the form:

$$\log_{10} P = \log_{10} A + k \cdot \log_{10} B$$

Applications include forecasting the demand for industrial plastics (Luker 1961) and describing the demand for methyl chloroform (Midgley 1989).

In the case of CFC-12 there are data for almost 40 years of use in refrigeration and air conditioning prior to the introduction of the Montreal Protocol and hence unconstrained by specific regulations. If \( P \) is the demand for CFC-12 in all forms of refrigeration and air conditioning in year \( i \) (year zero is 1946), expressed as \( 10^9 \) grams (thousands of metric tonnes), \( A = 616 \), \( k = 0.965 \) and \( B = 0.0115 \). The coefficient of variance, \( R^2 \), for this line is 0.989. An extrapolation of the line to 2025 will give an estimate of the underlying demand to that date for a refrigerant with properties like CFC-12. The result, together with the estimated 95 percent confidence limits, is shown in Fig.1. It should be noted that the annual consumptions for 1986 to 1991 were not included in the calculation; in those years the market was significantly distorted in anticipation of the effects of regulation.

A similar analysis of the historic HCFC-22 demand in AFEAS (1993) conveys the same sort of picture. In this case, the values in equation (1) are 450 for \( A \), 0.955 for \( k \) and 0.0327 for \( B \), with \( i \) equal to zero in the year 1960, and with \( R^2 \) equal to 0.982. Fig.1 shows the