CFC Substitute Substances and Technological Developments Related To Refrigeration/ Air-conditioning

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BACKGROUND

In the year 1974 report was published in NATURE magazine warning that certain CFCs were being added to environment in ever increasing amount and are responsible for destruction of ozone layer subjecting the earth to harmful solar ultraviolate radiation.

These CFCs are not being destroyed in the troposphere or lower atmosphere and in fact were drifting to stratosphere having a life span upto 120 years in the lower atmosphere and it takes decades for them to drift into stratosphere.

In the stratosphere which is around 10 to 20 miles above earth, these CFCs are transformed into chlorine items and destroy earth's protective ozone layer.

The recent findings also indicate that CFCs are contributing to green house (warming effect).

The green house effect is caused by presence of certain gases in atmosphere who form an insulating layer allowing the sun's heat to reach earth but preventing all of the energy radiated by the earth escaping.

In 1987 NASA research corroborated the theory of ozone depletion with photographs taken over southern hemisphere polar plots culminating in the Montreal Protocol signed between major developed/developing countries resulting in severe curtailment in production of some of the CFCs and banning by the turn of the century.

Major uses of CFCs currently being used world over are as indicated in Figure 1.This paper concentrates on use of CFCs in Refrigeration/Airconditioning which is around 35%.

Figure No.2 also shows the consumption pattern countrywise from which it can be seen that India and China together consume approximately 2% CFCs.

From the Figure 3 it can be seen that the per capita total consumption of CFCs in India is around 0.006 Kg whereas in USA it is 1.22 Kg(0.92) and in Europe it is 0.93 Kg(0.81) and in Japan 0.91(0.52) Kg.The figures in the bracket indicate consumption of R 11 & R 12.

The total quantity of refrigerant including R 22 produced in India are in the region of 4000 to 5000 tons/per annum whereas production in USA is around 400,000 tons, in UK it is 1,30,000 tons and in Japan it is around 80,000 tons.

Now let us have a look at the consumption pattern of each individual refrigerant. If we look at the Figure 4, it can be seen that CFC 22 has the maximum utilisation in refrigeration amounting to nearly 77% whereas CFC 11 and CFC 12 contribute only 10.8% to 10% of the total consumption.

All the CFCs are not equally harmful and in order to understand the pattern further it is essential to go through the ozone depleting potential of each refrigerant. From Figure 5 it can be seen that R 11, R 12, R 113 and R 114 are the CFCs responsible for contributing to be ozone depleting problem.

Similarly from Figure 6 it can be seen that R 12 is more harmful than R 22 from Greenhouse effect. R 22 being comparatively safe has been excluded from the legislative action.

Out of these four refrigerants kwhich are causing maximum damage, India currently produces R 11 and R 12 only whereas remaining two are not currently manufactured.

It could therefore be worthwhile to analyse use of these two refrigerants and find out whether these could be substituted with more environmentally friendly refrigerants.

Let us start looking at R 11 and its uses. R 11 is mainly for centrifugal refrigeration chillers and the present statistics indicates that approximately 4000 centrifugals are produced in United States every year whereas in India only around 50 centrifugals are being produced.

The first major task would therefore be to redesign centrifugal compressor for making them compatible with R22 refrigerant or any other refrigerant. There are few manufacturers in the world who are currently producing R22 centrifugal. However, 95% centrifugals still use R 11. A typical R 11 machine with a 16" dia impeller wheel operates at around 12000 rpm. If one is to design an R 22 machine of equal capacity, it would have a diameter of 3.8" and would operate at 36000 rpm speed. In the lower capacity ranges therefore it becomes difficult to design a machine with R 22 refrigerant. Currently the new refrigerant suitable HCFC 123 has been successfully tried with centrifugal machines and the efforts are going on to study the properties of this newly developed refrigerant and it is hoped that in few years use of R11 would be phased out for centrifugal machines.

It is also worthwhile to look at the alternate technologies in place of centrifugal applications and the screw compressors using ammonia or R 22 are currently available right from 20 tons upto 2000 tons. This technology is advanced in Eurupe and is catching up fast in USA and it can be proudly said that India has already adopted this technology for use in the country and there are more than 50 to 60 installations currently using indigenously manufactured screw compressors.Operating costs of screw chillers are comparable to those of equivalent sizes centrifugals in the airconditioning ranges. One can therefore confidently say that it is not a must to use centrifugals and R11 refrigerant if one wants to install plants using environmentally friendly refrigerants without spending on additional energy costs. The problem therefore basically has to be solved for the machines which are already in existence and still having a life span of another 15 to 20 years.

USE OF R 12

From the consumption pattern of R 12 used world over(10%), it would be seen that this refrigerant is mainly used in household domestic refrigerators, commercial display cabinets for food preservation, car airconditioning units and water coolers.

In certain cases it is possible to replace R 12 with R 22. However, for low temperature applications R 12 still dominates the market.

In changing the existing systems operating on R 12 with R 22 they are likely to create problems unless the complete system is redesigned keeping in mind following:

R 22 has 40% higher latent heat than R 12 and R 502 and the plants are likely to suffer from liquid carryover. In case of R 22 a little liquid leaving evaporator may not get fully evaporated since its latent heat is high.In multiple evaporator system or where rapid changes in the suction conditions take place, liquid carry over is most likely,especially after defrosting.

It would therefore be worthwhile to use accumulator or otherwise this may result in significant increase in failure rates due to liquid slugging.

Although R 22 gives about 30% more capacity than R 12 leading to smaller displacement compressor for the similar capacity, it requires more driving power per unit displacement than R 12 and therefore a larger motor is necessary.

Similarly R 22 plants have to be designed to withstand higher pressures as working pressures and temperatures of R 22 are much higher than R 12.

Another important criteria to be kept in mind is R 22 is less miscible with oil than R 12 hence accessories like oil separator in some systems may be needed or redesigning of piping for proper oil return to compressor has to be done. Crankcase heater would also be necessary for the compressor since R 22 is heavier than oil.

If all the above factors are kept in mind it may not be difficult to visualize that R 12 would be replaced with R 22 especially with the development of new types of compressors such as scroll compressors and mini-screw compressors.

In India the use of R 12 is mainly for domestic refrigerators and for bottle coolers whereas R 12 in most of the developed countries is also used for car airconditioners and display cabinets. The production of cars and that too also fitted with airconditioning units is insignificant in India and the same applies to display cabinets. The table given hereunder gives the statistics of domestic production of refrigerators,water coolers and room airconditioners out of which only refrigerators and water coolers use R12 whereas Room Airconditioners are already with R 22. If we have to compare, the No.of units manufactured in United States(figure 4) in 1988 are 46,37,300 units whereas in India the domestic refrigerators produced in the year 1988 are 8,97,000.

Production Statistics of Refrigerators, Room Airconditioners and Water Coolers in India

Year	Refrigerators	Room Airconditioners	Bottle coolers
1974	1,02,782	25,808	797
1975	1,04,951	8,708	506
1976	1,06,427	14,375	377
1977	1,40,167	19,757	363
1978	1,78,123	19,894	582
1979	2,10,630	24,616	895
1980	2,77,743	23,851	1,073
1981	3,15,131	30,116	1,786
1982	3,59,213	28,227	1,018
1983	4,59,828	26,065	560
1984	5,20,000	28,000	1,200
1985	6,58,717	33,487	999
1986	5,92,515	37,236	1,200
1987	6,80,875	38,417	820
1988	8,97,508	34,506(46,37,300) USA	828
Average charge of R 12 per Unit			
	170 grams	1000 grsms	600 grams

Having analysed the problem of substituting R11 and R12 with R22 and use of alternate hardware such as screw compressors, it is also worthwhile to analyse what are the alternate refrigerants or technologies available and can be pursued further which would lead to energy savings without damaging the environment.

When we look at the basic requirements of refrigerating properties(Figure 7) and the availability of various other refrigerants, we have to take cognizance of Ammonia to begin with.

AMMONIA

The first choice falls on age old refrigerant, ammonia. Ammonia is environmentally safe as it consists of completely biodegradable elements. However, it has been out of limelight for a long time. Ammonia is lighter than air and would tend to rise and dissipate fairly quickly unlike heavy CFCs.If ammonia leaks, it can cause eye and lung irrigation and hence has been out of fashion after availability of CFCs.(Fig.8)

Thermodynamically ammonia has excellent properties. Its heat transfer coefficients are superior and the power consumption per ton of refrigeration is the lowest. It is cheap, readily available and most of the refrigeration engineers have the experience of using ammonia. In fact even today many industrial refrigeration systems still prefer ammonia. It has higher cooling capacity per ton compared to other CFCs.Plant can use readily available material like steel.

It is also the most preferred refrigerant for ice plants, cold storages, industrial process cooling plants where trained skilled operating staff is available for maintenance.

The International Institute of Ammonia Refrige- ration is working actively to make this refri- gerant more popular and the hard-liners veterans and developed countries have started looking afresh for use of ammonia wherever possible.

Use of ammonia based in direct cooling systems for multistoreyed airconditioning can be adopted straightway where chilled water is circulated for comfort airconditioning. The use of ice plant systems with ammonia as refrigerant where ice is built during night time and the chilled water is produced during the day for comfort airkconditioning is being adopted in many developed countries.

Experiments have been tried out in many metropolitan cities where the chilled water can be supplied as utility similar to electricity supply and provide meters at the consumption points. Central plant would generate chilled water and can be piped to the various buildings. In fact in USA as early as in the year 1906 liquid ammonia was piped over a distance of 6 miles. Similarly the brines can be also piped over shorter distances. One might therefore contemplate such a system delivering chilled water to a group of airconditioned buildings in city. The chilled water being produced in large plant using ammonia as refrigerant and using large screw compressors.

The properties of ammonia have to be studied in greater depth from toxity and flamability angles and with the development and the status of present technology safety standards and added controls right from the stage of designing, engineering and manufacture could lead to safe ammonia installation.The development of canned motors could also make hermetic ammonia compressors possible.Ammonia circulation pumps are already in existence.

REFRIGERANT MIXTURES

Mixtures including Azeotropes and nonazeotropes have been of interest for many years at least from 1970s. These have to be now looked afresh in view of limited energy availability and environmental concern.

Although work on substitutes for pure refri- gerants is vigorously on, the goal is not likely to be realised so soon. Some system hardware modifications to optimise thermal performance, oil compatibility and costs have to be seen.

Environmental constraints reinforce the need for tailored working fluids designed to meet increasingly stringent specifications and non azeotropic mixtures offer a viable alternative.

ABSORPTION SYSTEMS

The use of absorption systems with Lithium Bromide and water mixture have been in use since early 50s. However, these systems require heat. Most use steam and are economically viable where waste steam is a bi-product of an industrial operation.

Absorption system uses more energy than centrifugals. The co-efficient of performance of these machines is very low. Presently, some companies have introduced three stage absorption machines and with increasing electricity charges these would workout to be economical in certain applications.

CRYOGENICS

Alternatives like cryogenic cooler may be feasible. However, technical problems with size and design for alternative use in automobiles and trucks and other such applica- tions have not been overcome yet. Prototype systems developed by Canadian firms have already been fitted on truck in USA.

THERMO ELECTRIC REFRIGERATION

In early 50s confident predictions were made about the future of thermoelectric refrigeration. Graphs were produced showing how the efficiency would be improved with the newer materials. However, this has not happened.

Future of thermoelectric refrigeration seems to depend on finding new types of material. With the current development of semi-conductors and the super conductors, it may be possible to discover newer materials in the years to come which could make this process commercially viable.

LIQUID NITROGEN

Use of liquid nitrogen or solid/liquid carbon to a limited extent is being made for refrigeration applications. Thermodynamic process of producing liquid nitrogen at $-196^{\circ}C$ in order to refrigerate at $-30^{\circ}C$ is expensive in energy terms. British Oxygen has set up a chain of liquid nitrogen supply for the transport refrigeration and this has worked successfully in U.K.

SOLAR ENERGY

In India there is abundant solar energy and it was hoped in early 70s that solar energy can be effectively used for airconditining. Many buildings world over have been fitted with solar airconditioning equipment on experimental basis. However, it is not presently working out to be economical with vapour compression systems, since efficiency of solar panels currently available is low and cost is high. Presently the area occupied by the solar panels is practically the same area as has to be airconditioned and it therefore does not become feasible to make use of solar energy especially for multi-storeyed buildings. With the advent of new materials and thereby efficient solar panels it is possible to visualise that many airconditioning plants would be switching over to solar energy.

RECYLING & RECOVERY

After going through the alternatives and various options available, it is also essential to concentrate on developing units for recycling and recovering refrigerants from the systems as well as from other materials such as insulating materials. Many companies have produced refrigerant recovery systems.

When the refrigerated cabinet is broken for scrapping, insulation begins to break down releasing refrigerant into the atmosphere. To reclaim refrigerant from insulation by compressing scrap system insulation in a sealed chamber and then collecting the gas as it is forced out, some manufacturers have started paying attention to these aspects.

TRAINING

It has also become essential to establish codes and norms as well as precise definition of professional qualifications of operators and technicians as well as technical competence of companies in safe handling of refrigerants and design of systems leading to a certificate of competence.

In conclusion, one can say that we have all the hardware available in terms of compressors, heat exchangers, controls and safety standards as well as determination to make use of other technologies and with proper Government support as well as legislative incentives it is not at all difficult to switch over from environmentally harmful refrigerants to safe and energy efficient installations.

R.P.Paranjpey
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FIGURE 1

END USES OF CFCs

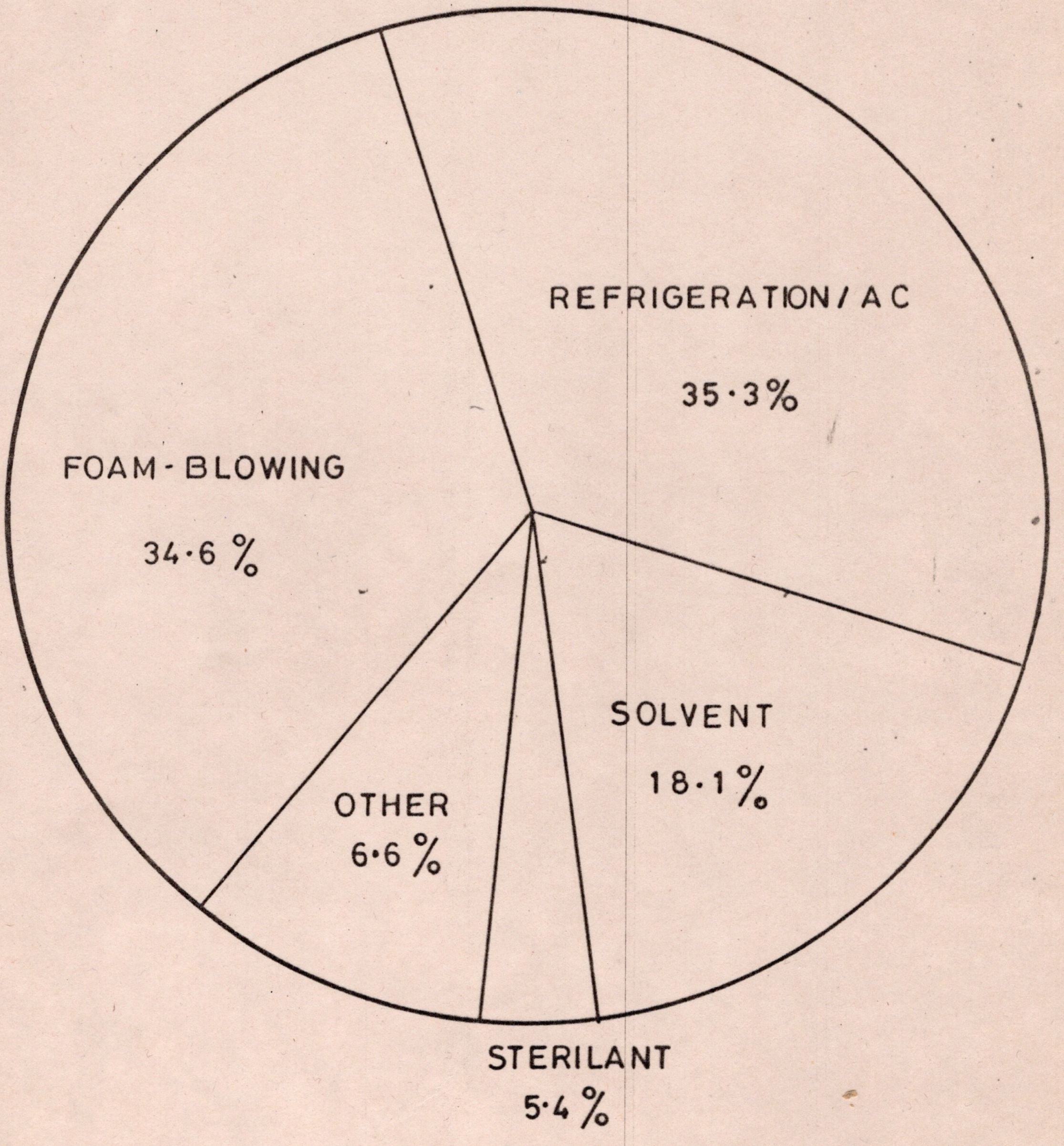


FIGURE 2

APPROXIMATE CONSUMPTION OF CFCs BY COUNTRY/ REGION

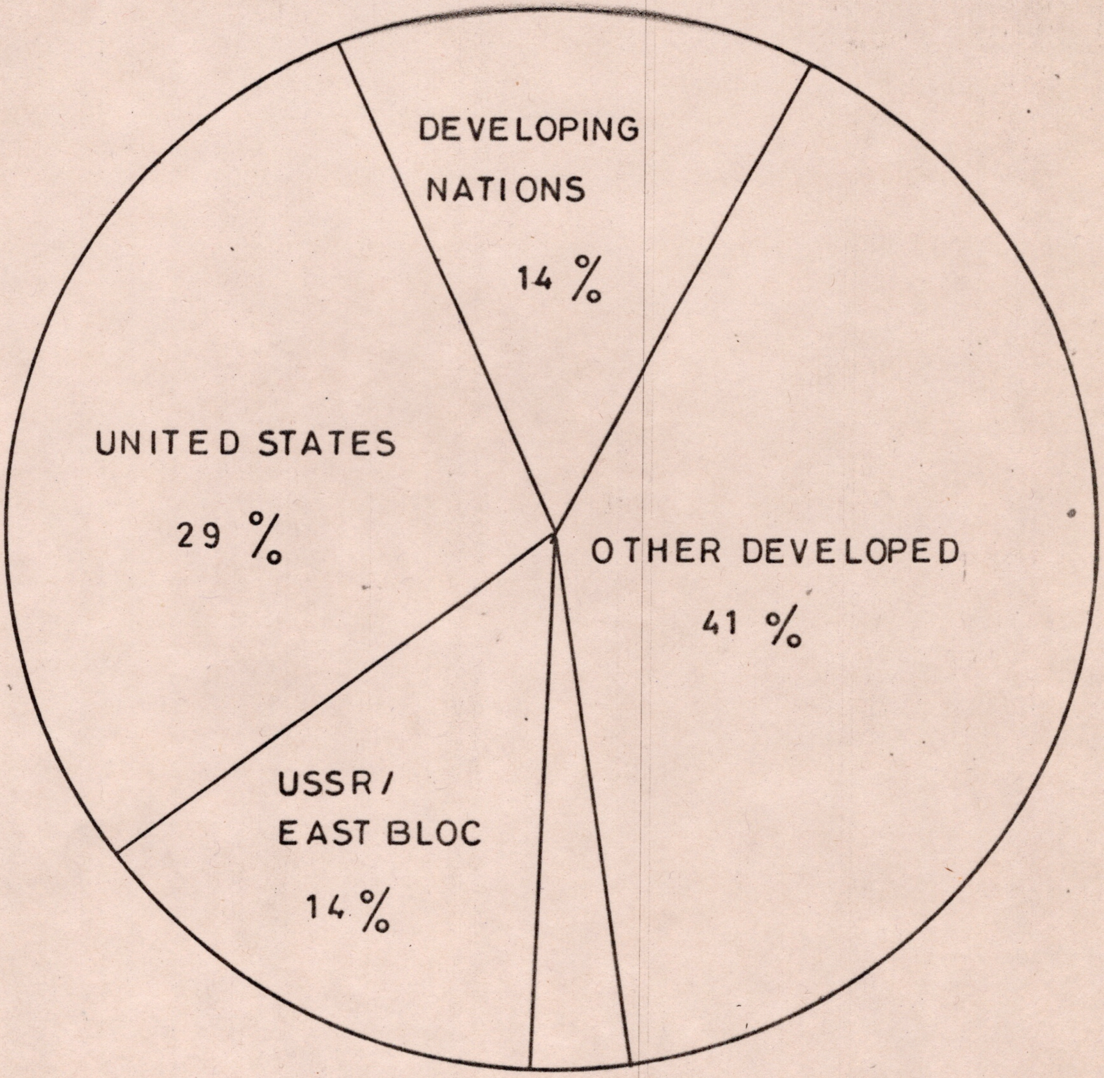
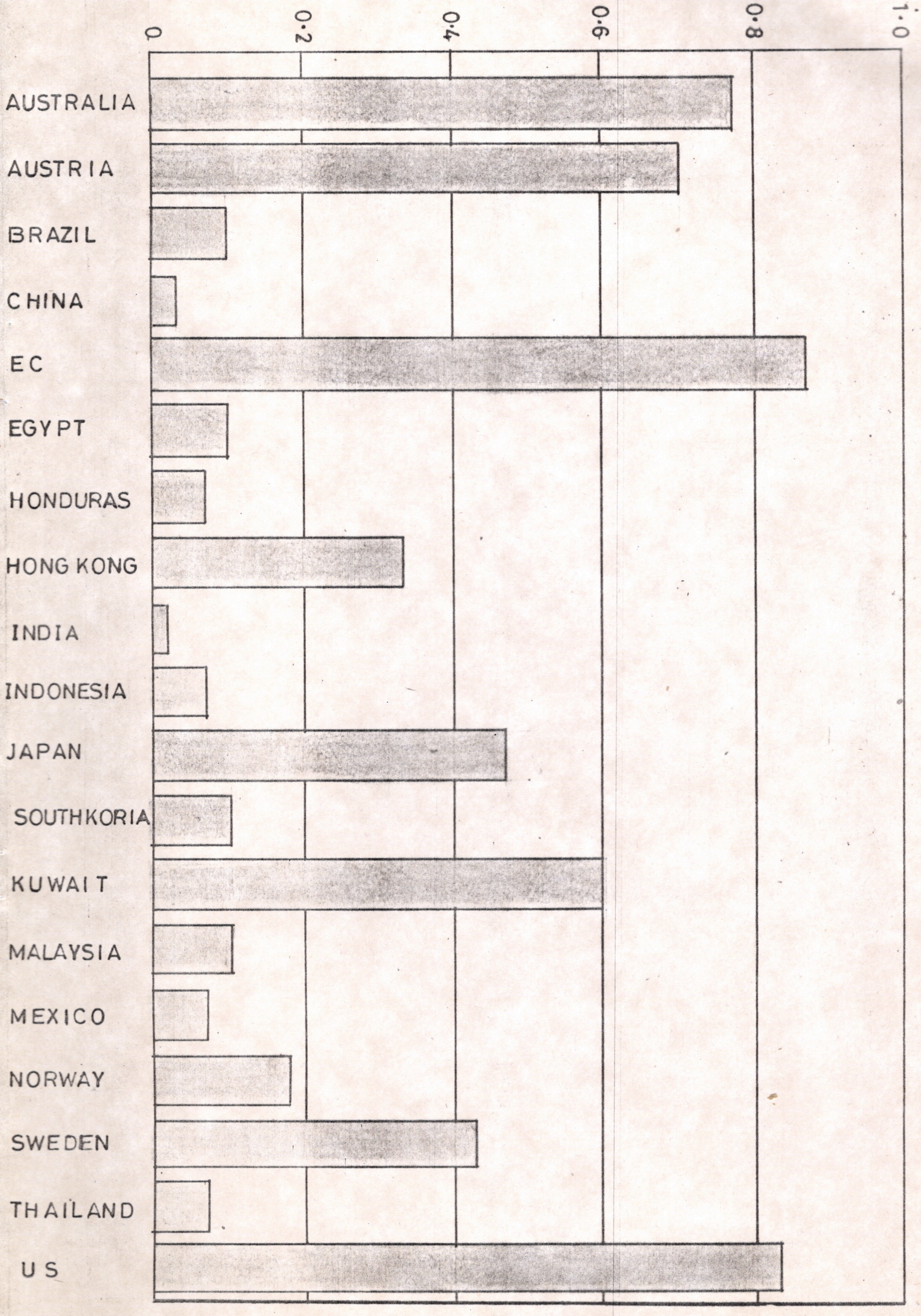


FIGURE 3

KILOGRAMS OF CFC·11 AND·12 USED PER CAPITA, 1985



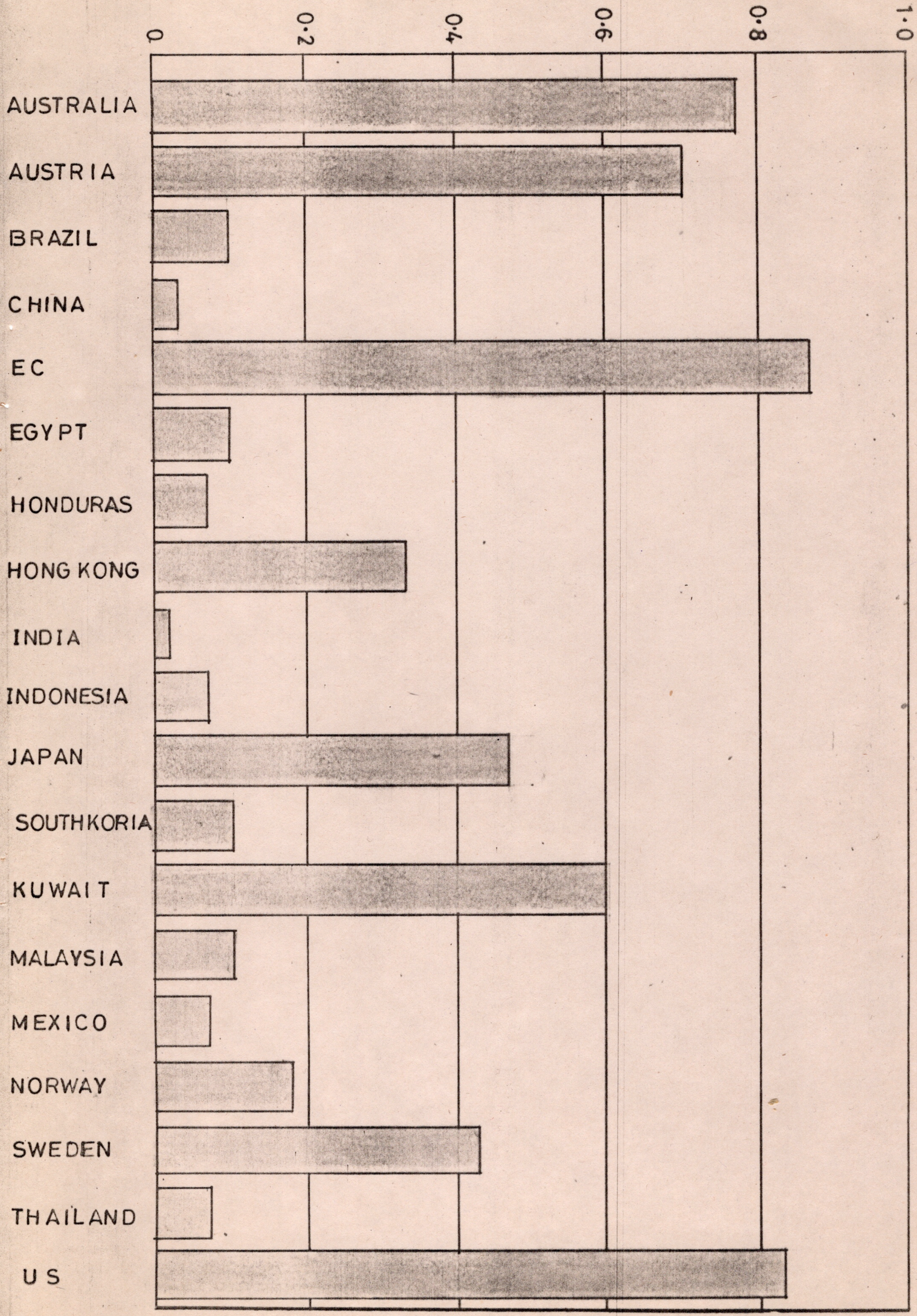
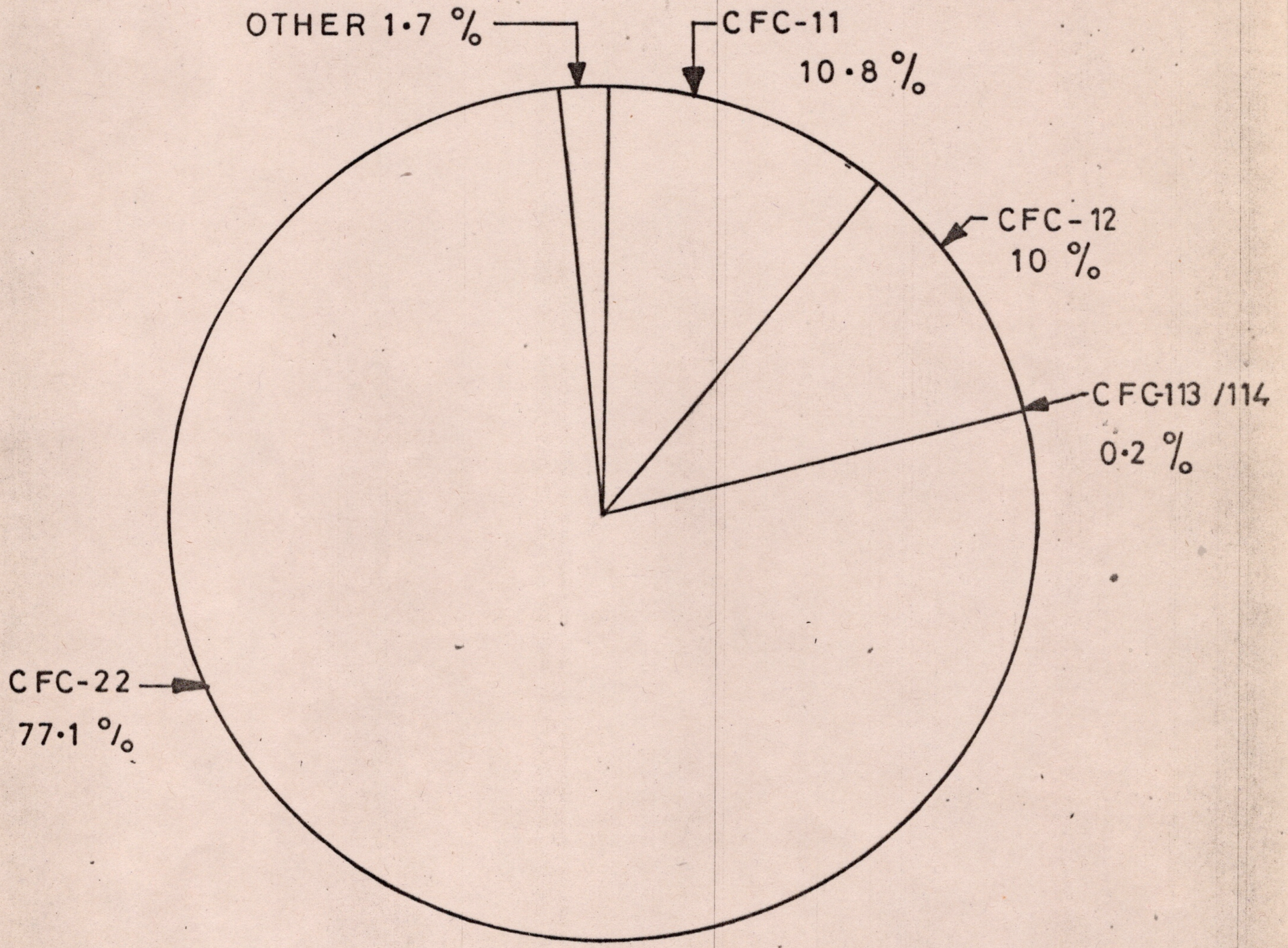


FIGURE 3

KILOGRAMS OF CFC·11 AND·12 USED PER CAPITA, 1985

FIGURE 4



CONSUMPTION PATTERN

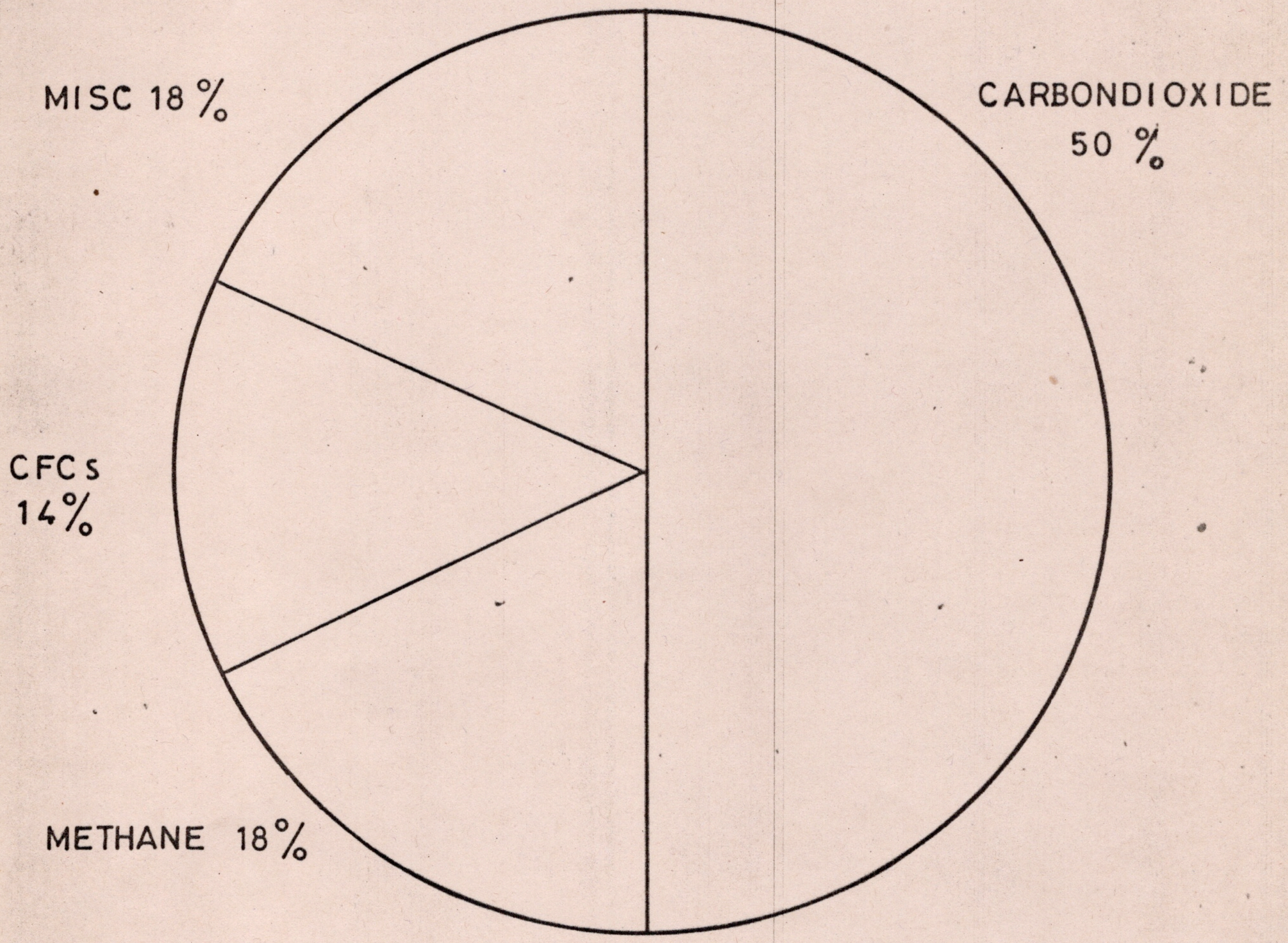
FIGURE 5

Ozone depletion potential of various refrigerants are as under:

Refrigerant	POD	Equivalent pounds
R 11	1.00	1.00
R 12	0.86	1.16
R 113	0.80	1.25
R 114	0.60	1.67
R 115	0.32	3.13
R 502 (Azeotrope of R 22 and 115)	0.19	5.26
R 22	0.05	20.00

FIGURE 6

GREEN HOUSE EFFECT



	GREENHOUSE STRENTH
CARBONDIOXIDE	1
METHANE	30
CFC 12	10,000
HCFC 22	700
CFC 502	10,000
HFA 134a	1,000

(FIGURE 8)

COMPARATIVE REFRIGERANT PERFORMANCE PER TON

BASED ON 5 F EVAPORATION AND 86F CONDENSATION

(ASHRAE FUNDAMENTALS)

REFRIGERANT	R 22 CHLORODIFLUOROMETHANE	R 717 AMMONIA	R 12 DICHLORODIFLUOROMETHANE
EVAPORATOR PRESSURE, PSIG	28·2	19·6	11·8
CONDENSING PRESSURE, PSIG	158·2	154·5	93·3
COMPRESSION RATIO	4·03	4·94	4·08
NET REFRIGERATING EFFECT, BTU/Lb	70	474·4	50
REFRIGERANT CIRCULATED, Lb/MIN	2·86	0·422	4·00
LIQUID CIRCULATED CU.IN/MIN	67·4	19·6	85·6
SPECIFIC VOLUME OF SUCTION GAS, CU.FT/Lb	1·24	8·15	1·46
COMPRESSOR DISPLACEMENT, CFM	3·55	3·44	5·83
HORSE POWER HP	1·011	0·989	1·002
COEFFICIENT OF PERFORMANCE	4·66	4·76	4·70
COMPRESSOR DISCHARGE TEMP. F	128	210	101