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Open-ended Working Group of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer
Thirty-third meeting
Bangkok, 24–28 June 2013
Items 3–13 of the provisional agenda*

Issues for discussion by and information for the attention of the Open-ended Working Group of the Parties to the Montreal Protocol at its thirty-third meeting

Note by the Secretariat

Addendum

1. The present addendum contains new information on the issues on the agenda for discussion by the Open-ended Working Group of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer at its thirty-third meeting that has become available since the drafting of the first addendum to the relevant note by the Secretariat (UNEP/OzL.Pro.WG.1/33/2/Add.1).

2. The Technology and Economic Assessment Panel's 2013 progress report, volume 2, which responds to decision XXIV/7, was finalized and made available on the Ozone Secretariat meeting portal on 16 May 2013. The report is a draft for the consideration of the Open-ended Working Group and a final report will be prepared for the Twenty-Fifth Meeting of the Parties to be held in October 2013.

3. The draft report catalogues commercially available, technically proven, environmentally sound and emerging alternatives to ozone-depleting substances in the four sectors of use of such substances. The executive summaries of the chapters on those four sectors are set out in the annex to the present addendum. They are presented as received from the Panel; they have not been formally edited by the Secretariat. The parties are encouraged to read the full draft report for further and more detailed information, including on the methodologies and definitions employed by the Panel.

4. With regard to agenda item 7 (b) on the status of the membership of the Panel and its technical options committees, information on the status of the reappointment of the Panel's co-chairs and members for four-year periods in accordance with previous decisions and on the status of renomination of the Panel members is contained in the note by the Secretariat (UNEP/OzL.Pro.WG.1/33/2, paragraphs 27 and 28, respectively). In the meantime, Brazil has renominated Mr. Roberto Peixoto as co-chair of the Refrigeration, Air-conditioning and Heat Pumps Technical Options Committee.

* UNEP/OzL.Pro.WG.1/33/1.

Annex

May 2013 report of the Technology and Economic Assessment Panel, Volume 2

Decision XXIV/7 Task Force Report, Additional Information on Alternatives to ODS

(Draft Report for the Thirty-third Meeting of the Open-ended Working Group)

Executive summaries of the chapters

3 Refrigeration and air conditioning

Executive Summary

Initially, the chapter provides generic information relating to selected alternative substances. This includes a description of five classes of alternatives:

- Ammonia (R-717)
- Carbon dioxide (R-744)
- Hydrocarbons (HC-290 and others)
- HFCs (medium and high GWP), and
- HFCs (low GWP)

For each alternative, general efficiency aspects, cost effectiveness and barriers and restrictions are given. Subsequently, additional information, including current trends, is presented in the sub-sector specific sections that follow, wherever applicable.

For this report it was considered under the current circumstances to discuss a small number of currently unassigned refrigerant blends where it is anticipated that they are close to commercialisation and receiving R-number designations.

In **domestic refrigeration**, the main refrigerants used are hydrocarbon HC-600a (isobutane) and HFC-134a. More than 50% of current new production (globally) employs HC-600a, the remainder uses HFC-134a.

HC-600a continues to be the main alternative to HFC-134a. Concerns in connection with the high flammability no longer exist for the low charges applied. No new alternative has matured to become energy-efficient and cost-competitive. Considering the product costs, HC-600a is less expensive than HFC-134a, but additional investment cost for HC-600a products are due to the larger size of compressors. Production cost for refrigerators can be higher due to the requirements for safety systems.

Initial developments to assess HFC-134a replacement with HFC-1234yf have begun, but is not being pursued as a high priority. Still HFC-1234yf has demonstrated the potential for comparable efficiency to HFC-134a. The lower flammability makes its application easier in countries with strong reservations about HC-600a. R-744 (CO2) is also being evaluated, but its application implies additional costs.

In **commercial refrigeration** stand-alone equipment HFC-134a and R-404A are still the dominant refrigerants. HC-600a and HC-290 are used for small commercial equipment with refrigerant charges varying from 15 g to 1.5 kg. R-744 is mainly used in vending machines; the technology is operating well but it is a technical challenge and only one supplier is able to provide an efficient system. The small additional cost associated with safety in HC equipment is integrated in the price, and is not much different compared with HFC equipment. Where it concerns low GWP HFCs, HFC-1234yf can replace HFC-134a in any application. Due to its comparable energy-efficiency with HFC-134a, vending machines with HFC-1234yf have been introduced in countries such as Japan (two manufacturers). One of the lead compressor manufacturers of small reciprocating compressors is already producing them. Currently a main barrier is still (the wide) availability of the chemical.

Regarding condensing units, some new R-744 based units are sold in northern Europe, but the penetration in the market is slow. Several indirect condensing units with HC-290 or HC-1270 are operating in Europe with typical refrigerant charges varying from 1 to 20 kg, with good energy efficiency. Costs for these HC based systems are typically 5 to 15% higher compared with HFC systems.

HFC-134a, R-404A, and, at a small level, R-410A are HFCs of choice for condensing units. As in all other commercial applications, high GWP HFCs are seen as short-term options.

In supermarket refrigeration, the current options for large European commercial companies area HFC-134a system at the medium-temperature level connected to an indirect system or to a R-744 direct system for the low temperature level since this is a global option for all climates. Ammonia is used in indirect centralised systems for large capacities; usually R-744 is used at the low-temperature level. Due to safety issues the number of installations so far is limited. For applying lower GWP options, HFC-134a can be replaced by HFC-1234yf or HFC-1234ze where the lower flammability of these refrigerants can be addressed during the design stage. For non-flammable options, small temperature-glide blends --such as N-13 and XP-10-- can also be used in existing facilities. Two-stage R-744 systems for the medium-temperature level and the low-temperature level have taken a certain market share in Europe and are now installed in more than 1000 stores. R-744 trans-critical cycle developments are on-going to make the technology more energy-competitive under higher ambient conditions. The additional cost is again limited to 10 to 15%. For the non-low GWP refrigerants, R-404A is currently the dominant refrigerant, even if it is now replaced in new installations by HFC-134a at the medium-temperature level. R-407F is proposed as an intermediate option. There are also non-flammable options with lower GWP such as the HFC blends N-40 and DR-33. Two-stage R-744 systems for the medium-temperature level and the low-temperature level have taken a certain market share in Europe and are now installed in more than 1000 stores. R-744 trans-critical cycle developments are on-going to make the technology more energy-competitive under higher ambient conditions. The additional cost is again limited to 10 to 15%.

The refrigerant of choice for transport refrigeration systems in non-Article 5 countries is HFCs. R-404A has become a preferred choice for practically all trailers and large trucks. HFC-134a is used in small trucks and vans. Testing of low-GWP HFC and non-HFC alternatives are in progress elsewhere, but not one option seems viable in the short term. The main issue is that the performance of R-404A is difficult to meet. Current and previous tests with trucks using R-744 suggest that introduction of R-744 will be possible when more efficient compressors with more than one compression stage, which are under development, will be commercially available. The use of hydrocarbons (mainly HC-290) in truck refrigeration units has been tested; they would be the preferred choice because they can provide lower energy consumption in the order of 20% or more. HFC-1234yf can be an interesting alternative to HFC-134a due to its lower discharge temperature.

On vessels, hydrocarbons are technically feasible, but the strict safety concerns currently do not favour application of flammable refrigerants aboard. Natural refrigerants have been commercialised to a small extent aboard marine vessels worldwide. For European fishing vessels highly efficient ammonia-CO2-cascade systems are the systems of choice.

Over 90% of the large **industrial refrigeration** installations use R-717 whereas the market share of R-717 is only 5% (India and China) to 25% (Europe and Russia) for smaller industrial refrigeration systems. Energy efficiency is in general 15% higher than HFCs systems. Hydrocarbons are not widely used, other than in situations where safety measures are already required, e.g. in a petrochemical plant.

In Small Self-Contained (SSC) **air conditioners** R-744 is not widely considered for use. The main barriers for SSC air conditioners are related to efficiency and cost implications. Due to efficiency implications, the use of cooling only R-744 systems is not really feasible. However, there are developments on units for specific purposes, where both cooling and heating is needed. HC-290 has been used in portable ACs for many years and several companies are producing them. Window units are also under development. HC-290 seems to be preferred over HC-1270 for smaller capacity systems.

R-410A is used in most SSC ACs, where HCFC-22 is not used. It is feasible to use HFC-32 in SSC ACs, for example, where R-410A is already used. HFC-32 energy efficiency deterioration due to high ambient is a few per cent worse than HCFC-22, but not as severe as R-410A.

HC-290 has been used in split ACs for many years on a limited scale but now some companies are developing and producing them on a larger scale. Although HC-290 seems to be the preferred HC option, HC-1270 is under evaluation by some companies. HC-290 units are available from several companies. Currently, no split air conditioners are available using R-744, although some studies have been carried out.

In hot **water heat pumps and space heating heat pumps**, R-717 is used fairly widely in capacities from 250 kW to very large/industrial-scale (>1 MW). Such systems are located outside or in special machinery rooms in order to handle the higher toxicity characteristics. As with R-717 systems in general, the main barriers are related to the minimal capacity required for cost-effectiveness and certain national regulation controlling installation. A large number of manufacturers globally are producing domestic and small commercial sized hot water heating heat pumps using R-744. Generally, the efficiency that can be achieved by R-744 in hot water heaters is much higher than that of other refrigerants. It is feasible to use HFC-32 in hot water heat pumps, for example, where R-410A is already used. HCs, particularly HC-290, had been used widely in Europe for small (domestic) heat pumps, and there are also large commercial-sized heat pumps being marketed, which use HC-290 or HC-1270. It is feasible to use HFC-32 and the L-20 blend in space heating heat pumps.

Considering the use of low-GWP refrigerants in reciprocating and screw **chillers** the following describes the current situation. R-717 is used fairly widely for process refrigeration, food storage facilities and air conditioning. The efficiency of R-717 is high for chillers in both medium and high temperature applications. The barriers for chillers are consistent with R-717 systems in general. R-744 is now used in reciprocating chillers by many manufacturers. As with other types of systems, the efficiency is compromised with increasing ambient temperatures. The main barrier for R-744 chillers is the poorer efficiency in climates with consistently higher ambient temperatures. Both HC-290 and HC-1270 are produced by a number of manufacturers in Europe and some countries in other regions. There are certain barriers in the case of HC applications, depending upon chiller configurations.

HFC-1234ze(E) is a refrigerant that can be used in existing HFC-134a technologies with minor modifications (compressor sizing), and it has been trialled in systems in Europe. When used in reciprocating, scroll or screw type of compressors, it produces efficiency levels comparable to HFC-134a. In centrifugal compressors, this refrigerant produces efficiency levels slightly better than HFC-134a. HCFC-1233zd(E) can replace HCFC-123 (a low-GWP HCFC) in low pressure centrifugal chillers with slightly better efficiency levels. In chiller applications, both HFC-1234ze(E) and HCFC-1233zd(E) should perform very well in warm climates, due to their high critical temperatures.

Both R-407C and R-410A are widely used in positive displacement chillers as is HFC-134a. HFC-134a is used widely in various capacities of centrifugal chillers..

HCs are used to a limited extent in centrifugal chillers typically within the petro-chemical industries where hazardous area protection is already in common use.

In **mobile air conditioning** systems (dependent on the country), the preferred option is to shift to HFC-1234yf, but the delayed market availability of this refrigerant seems to slow down the shift. Other future options are still being reconsidered by certain car manufacturers; in fact, this would be R-744, while staying with HFC-134a until R-744 would have been commercialised. R-744 has been demonstrated to be as efficient as the best in class HFC-134a system. However, the main barrier for R-744 systems has been the cost, as well as issues related to safety, compressor durability and leak detection.

A current barrier for HFC-1234yf is related to patent issues between the chemical manufacturers; where mass-production of low GWP HFC systems has been delayed. Even when e.g. the German car industry favours to stay with HFC-134a until R-744 would have been commercialised, the change from HFC-134a to HFC-1234yf seems to be the likely solution because the car industry favours global options for AC systems. This has been supported by LCCP analysis, which showed superiority of HFC-1234yf for most ambient temperatures.

Reduction of negative environmental impacts due to amounts that could have been or could be avoided

In the case of domestic refrigeration, the following can be stated. For the period 2010-2015, the use of HFC-134a (compared to CFC-12) would yield a lower negative environmental impact of 230 Mt CO2-eq. per year; the use of HC-600a (isobutane) would add another 33 Mt CO2-eq. annually. In practice, the entire global domestic refrigeration has been converted, with about 50% to HC-600a. So the conversion of all now (2013) remaining HFC-134a to HC-600a would yield a saving of about 17 Mt CO2-eq. annually.

Whereas relatively simple considerations give insight in the case of domestic refrigeration and similar other uses that do not have to deal with servicing etc., the question in the case of RAC sectors that needs a lot of servicing, is whether in making selections early a consideration of a pure R-410A environment or a pure hydrocarbon environment has any value for common practice. A change of 100% as of a given year to a certain refrigerant with a negligible GWP means that one would avoid 200,000 tonnes of HCFCs in a given year, and servicing amounts of HCFC-22 for the equipment that has not been manufactured in such a year during many future years, i.e., for a 15 years lifetime of the equipment it would be something like 2,400,000 tonnes over a period of 15 years, due to a conversion of 200,000 tonnes in a start-up year.

However, financial constraints will flatten the profile of the introduction of new technologies in new manufacture, and a conversion of 5-10% of the total per year would be a reasonable amount to assume as the maximum achievable.

The table below gives the approximate consumption in HCFC-22 (or HFC blends such as R-404A or R-410A) for non-Article 5 and Article 5 countries in the year 2013. It concerns commercial refrigeration and stationary air conditioning.

It assumes 40% of the consumption being used for new manufacture in developed countries, 20% of the consumption used for new manufacture in the developing countries. It assumes 10% of the new manufacture being converted to alternatives in a given year and gives the numbers for the reduction in negative environmental impact in that year, as well as the influence on the negative environmental impact (i.e., in many cases a reduction) over a period of 15 years after the conversion in manufacture, which is due to the reduction of the impact in the servicing amounts (assumed over a period of 15 years).

A change of 10% in the manufacture for commercial refrigeration in developing countries to HFC blends such as R-404A gives an increase in negative environmental impact of about 4 Mt CO2-eq., and an increase over 15 years in servicing of 32-64 Mt CO2-eq. (dependent on whether the servicing per year would be 50-10% of the original charge. Going from HCFC-22 to low GWP options (having an average GWP of 300) yields a decrease in negative environmental impact of 3 Mt CO2-eq and another 23-46 Mt CO2-eq reduction over the period of 15 years thereafter.

In particular for refrigeration and air conditioning, it will be clear that a conversion to alternatives with a low negative environmental impact is one of the first priorities. This holds in particular, because a change in manufacturing now will have consequences for many years to come, via servicing amounts. A calculation of the consequence in tonnes in the negative environmental impact should give an adequate first impression.

Countries	**Approx. Cons. (t)**	**Assumed in manufacture**	**10% of manufacture**	**Avoidance (Mt CO_2-eq.) per year**	**Avoidance via servicing in 15 years (Mt CO_2-eq.)**
Commercial refrigeration (2013)					
Non-Article 5 countries					
From HCFC-22 to HFCs**	40,000	16,000	1,600	-3.2	-10/ -20
From HFCs** to low GWP	40,000	16,000	1,600	5.4	16-32
Article 5					
From HCFC-22 to HFCs**	100,000	20,000	2,000	-4.2	32-64
From HCFC-22 to low GWP	100,000	20,000	2,000	3	23-46
Stationary Air Conditioning (2013)					
Non-Article 5					
From HCFC-22 to blends/410A	140,000	56,000	5,600	-2.2	17-34
From HFCs to low GWP	140,000	56,000	5,600	10.5	32-64
Article 5					
From HCFC-22 to blends/410A	400,000	80,000	8,000	-3.2	24-48
From HCFC-22 to low GWP	400,000	80,000	8,000	11.8	88-176

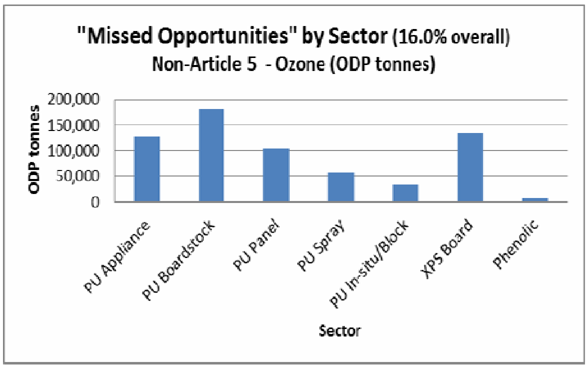
** HFCs in commercial refrigeration are given a GWP of 3800 (which would be the GWP of R-404A).
***Low GWP chemicals, which could be different types of blends etc., natural refrigerants, have been given an average GWP of 300.

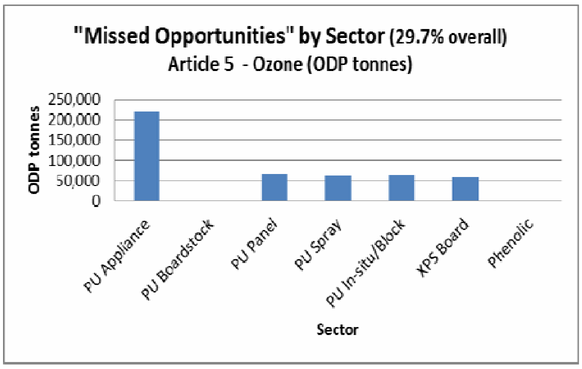
4 Foams

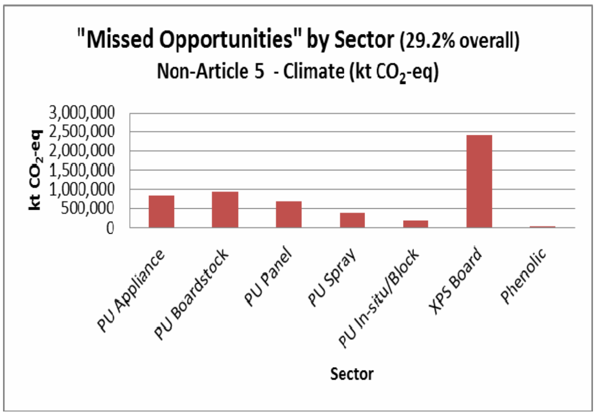
Executive Summary

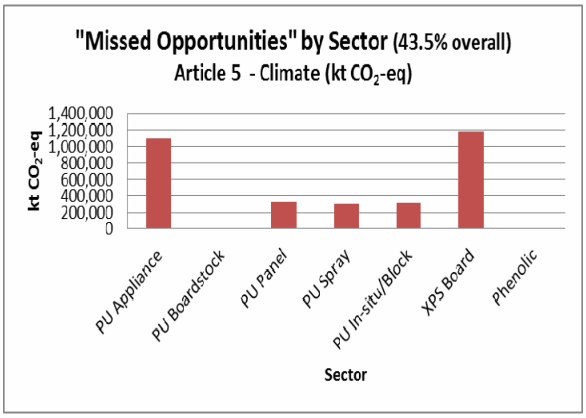
The foams sector has made transitions from its CFC baseline, through HCFCs in some cases, to either high-GWP or low-GWP non-ozone depleting solutions. As of 2013, the residual reliance on HCFC use in Article 5 regions rests to some extent in polyurethane appliance foams (often within commercial appliances), but mostly in PU Spray and XPS Board.

It is important to note that, of the 5.6 million ODP baseline footprint of the foam sector between 1990 and 2012, over 80% of the footprint was avoided. Similarly, for a cumulative baseline climate footprint of 26.3 billion tonnes CO2-eq over 66% has been avoided. This assessment has taken the rather stringent approach of not correcting for the 10 year grace period given to Article 5 Parties, so the avoided baseline percentages against regulatory requirements are considerably higher. A similarly stringent approach has been taken with respect to the availability of non-ozone depleting alternatives and low-GWP solutions. It has effectively been assumed that these were available throughout the period of analysis and thereby over-estimates the ‘missed opportunities’ in order to place a worst case perspective to the data generated and avoid subjective scenarios. The following graphs illustrate the missed opportunities analysed in this way for both ozone and climate:



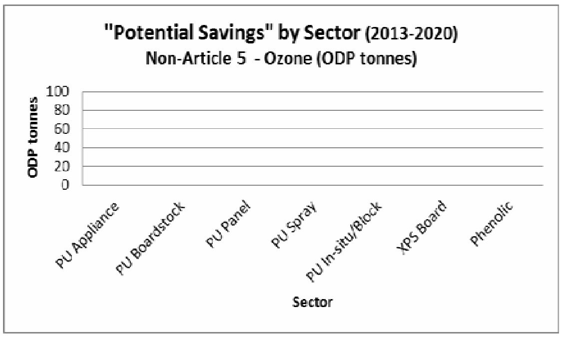


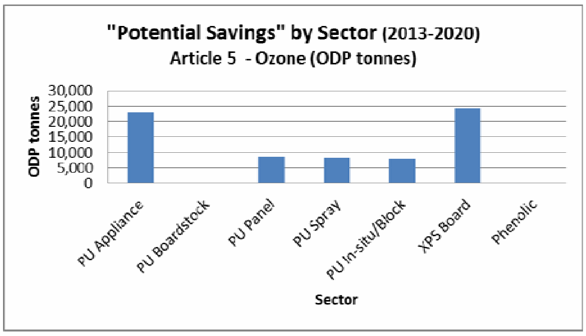


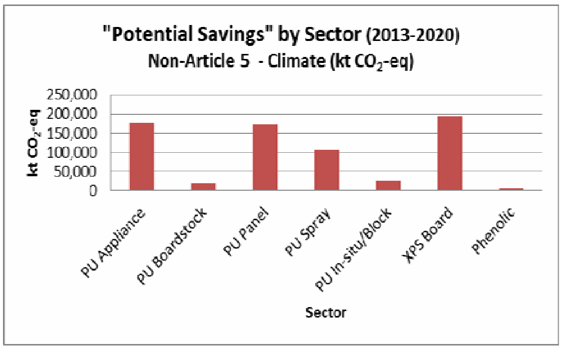


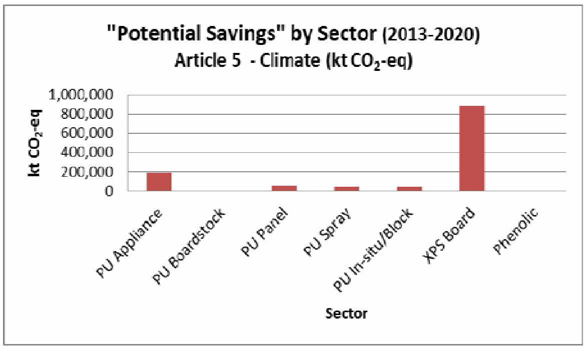
The reasons for these ‘missed opportunities’, especially for the XPS board sector, are fully explained in the foams chapter and it remains difficult to identify significant areas where the transition process could have been accelerated substantially given the constraints faced. It should also be noted that the effect of changes in thermal performance have not been factored into the climate assessment in view of the complex and non-determinable usage patterns to which most building insulation foams are subject.

Moving forward to assess the potential for further savings, the period of assessment has been limited to 2013-2020 in view of the uncertainties surrounding market growth in the foam sector beyond that date. However, it should be noted that the potential savings will be under-estimated by taking this relatively cautious approach. The following four charts show the potential savings available assuming an immediate transition in 2013. While recognizing that this is not possible in most cases, it does compensate to some extent for the relatively short assessment period:









Again, it should be noted that, although these savings are assumed to remove all of the remaining ozone and climate impacts for the period 2013-2020, the ozone-related savings represent only 2.3% of the footprint that would have existed without the Montreal Protocol. Similarly, the removal of the remaining climate impacts only represents 13.3% of the climate footprint that would have existed without the Montreal Protocol.

With HCFC Phase-out Management Plans now well into their first phase, it is clear that most of the significant sectors identified in Article 5 Parties are already being addressed. However, this is not necessarily the case in non-Article 5 Parties where the drivers for further transition need to come from the climate agenda, bearing in mind that the phase-out of ozone-depleting substances is already complete. Apart from regulatory intervention, one of the key drivers may ultimately be the improvement in thermal efficiency offered by low-GWP substitutes such as unsaturated HFCs, unsaturated HCFCs or blends containing them.

It is clear that the timing of further transitions is less critical to the environment than was the case for CFC phase-out, where delay had substantial consequences. There are still some difficult transitions to address (e.g. in the XPS sector) and it may be that waiting for the maturing of emerging technologies will offer better long-term solutions than forcing the transition too soon. Where this is unavoidable because of ODS phase-out commitments, it may still be better to consider a low-cost interim solution in order allow for a subsequent transition.

5 Fire protection alternatives to Ozone Depleting Substances

Executive Summary

Ozone depleting substances (ODS) used as fire extinguishants possess unique efficacy and safety properties that serve as a basis of fire protection systems where the application of water (by hose stream or sprinkler heads), dry chemical agents, or aqueous salt solutions is problematic. This is especially true in high-value, commercial electronics environments and in military systems, to name only two of many applications where such systems had many serious technical disadvantages.

Commercially available, technically proven alternatives to ODS for Fire Protection have been developed and include: halocarbon agents, e.g., HFCs and a fluoroketone (FK); inert gases, e.g., nitrogen and argon and their blends; carbon dioxide; water mist technologies; inert gas generators; fine solid particles (powders); dry chemicals; and aqueous film-forming foam. Several environmentally sound alternatives to ODS fire extinguishing agents for both total flooding and local applications uses have been introduced to the market. If an environmentally sound alternative agent works in any specific application, there is no barrier to its adoption other than economic considerations. Additional environmentally sound alternatives are presently under development that may increase the number of applications where environmentally sound alternatives are technically viable.

The production of PFCs and HFCs for use in fire extinguishing systems and portable fire extinguishers as well as the production of alternatives (without negative environmental impacts) to these agents for uses in the same applications is performed by very few manufacturers, all of whom treat the information on their historical, present and projected production as proprietary. Without a clear understanding of these production levels for the alternatives without negative environmental impacts, and also for the PFCs and HFCs, there is no basis for making a sound judgment about the overall utility of any alternatives in replacing PFCs and HFCs in the fire protection sector.

Nevertheless, we can say that the fire protection community has acted responsibly in dealing with what have turned out to be unsuitable alternatives from an environmental impact perspective. The availability of several HFCs that collectively could perform as well as the PFCs in certain applications, and at the same time present a more favorable environmental impact, led to the collapse of the use of PFCs in those applications.

However, the need for chemical agents remains as inert gases, water mist and other agents are not suitable for many fire protection applications that had previously used halon. HFCs have filled that role and, since about 2005, a fluoroketone (FK) has increasingly become more accepted. There is no evidence to suggest that this FK is or is not living up to the expectations of the fire protection industry, which is still evaluating alternatives that have low environmental impacts.

The use of HCFCs in fire protection is declining, with the only total flood agent being provided for the maintenance of legacy systems that are themselves phasing out. Only HCFC-123 is used in any quantity in portable extinguishers and if the development of 2-Bromo-3,3,3-trifluoropropene proves to be commercially successful, it would be the natural replacement for it and halon 1211 – particularly in the aviation industry.

6 Solvents

Executive Summary

The HCFC solvents currently used are HCFC-141b and HCFC-225ca/cb with ODP of 0.11 and 0.025/0.033 and GWP-100yr of 713 and 120/586, respectively. The elimination of HCFCs from solvent applications still leaves many options available. Many alternative solvents and technologies developed so far since 1980s are the candidates for HCFC alternatives, which include, not- in kind technologies such as aqueous cleaning, semi-aqueous cleanings, hydrocarbon and alcoholic solvents, and in-kind solvents such as chlorinated solvents, a brominated solvent, and fluorinated solvents with various levels of acceptance. However, no single option seems well suited to replace HCFCs completely.

Recently unsaturated fluorochemical HFOs (hydrofluoroolefins) with zero ODP and HCFOs (hydrochlorofluoroolefins) with negligibly small ODP are said to be under development. They have ultra low GWP (<10) and are expected to replace high GWP-HFC and low or moderate GWP HFE solvents. Among them, HCFOs are unique in their balanced solvency due to the presence of chlorine and fluorine atom in the molecule. If HCFOs with appropriate boiling points, low toxicity and enough stability to the practical use be on market, they may replace HCFCs totally in the future.