IMPACT OF THE MONTREAL PROTOCOL KIGALI AMENDMENT TO THE CHOICE OF REFRIGERANT ALTERNATIVES

F. POLONARA
UNIVERSITÀ POLITECNICA DELLE MARCHE
UNEP TEAP - RTOC

POTENTIAL IMPACT OF THE MONTREAL PROTOCOL KIGALI AMENDMENT TO THE CHOICE OF REFRIGERANT ALTERNATIVES

Fabio Polonara[1,5], Lambert J.M. Kuijpers[2,5], Roberto A. Peixoto[3,4,5]
[1]Universita' Politecnica delle Marche, Ancona (Italy), [2]A/genT Environmental Consultancy (Netherlands), [3]Instituto Mauá de Tecnologia, Sao Paulo (Brazil), [4]London South Bank University, London (UK), [5]United Nations Environment Program, RefrigerationTechnical Options Committee - UNEP RTOC

Abstract

The paper first gives a description of the HFC phase-down schedules as decided by the Montreal Protocol in Kigali, October 2016 and the potential impacts to the choice of refrigerant alternatives. Freeze dates and reductions for HFC consumption for the various country groups and possible impacts are summarized. Because national or regional HFC regulations in several developed countries are already influencing refrigerant choices, an analysis is presented in how far Kigali decided freeze-baselines and following reductions are expected to further steer near future refrigerant choices. Even before that the Kigali amendment will enter into force in 2019, low GWP alternative applications including those using ammonia, CO_2 and HCs may gain further market shares in both developed and developing countries, based upon the perception that already ongoing conversions will inevitably proceed in the marketplace. This process will be accelerated in the case of developing countries who may decide in favor of certain low GWP alternative choices early, ahead of the Kigali agreed HFC reduction schedules. Considerations are presented which low GWP synthetic and "natural" refrigerant conversions in the various R/AC sub-sectors could contribute to future compliance with the 2016 Kigali agreed HFC schedules under the Montreal Protocol.

*Even if the authors are UNEP-RTOC members, they intervene in their personal capacity

1. Introduction

Chlorofluorocarbons (CFCs), Hydro chlorofluorocarbons (HCFCs) and other ozone depleting substances (ODS) are potent greenhouse gases (GHG). The phase-out of these chemicals as mandated by the Montreal Protocol, and consequent resulting reductions of emissions and atmospheric concentrations have had an enormous contribution to climate protection, next to the original intent of the Montreal Protocol to protect the ozone layer. It has been estimated that the total avoided net annual ODS emissions would be equivalent to about 10 Gt $CO_{2\text{-eq}}$ in 2010, which is about five times the annual reduction target of the Kyoto Protocol for the period 2008–2012 (Velders et al., 2007).
According to studies and assessments (Velders et al, 2012, 2014) the climate benefit of the Montreal Protocol could be reduced or totally lost in the future if emissions of ODS substitutes with high global warming potentials (GWP), such as some HFCs, continue to increase. Based on these research results, Parties to the Montreal Protocol started discussions (based on proposals) on an amendment to add HFCs and control schedules to the Montreal Protocol in 2009.

Hydrofluorocarbons (HFCs) were largely developed and promoted as alternatives to ODS and have been used in the last 30 years in several sectors, mainly as refrigerant in refrigeration, air conditioning and heat pumps (RACHP) applications. HFCs are greenhouse gases that can have high or very high-GWP, up to 14'800. (UNEP, 2016)

The main issues that were thought to favor the inclusion of HFCs as controlled substances under the Montreal Protocol presented by the countries proposing amendments were: HFCs were developed and promoted as a result of Montreal Protocol CFC and HCFC control measures; the framework built by the Montreal Protocol for the phase out of CFCs and HCFCs in the sectors where HFCs are being used, would be the most appropriate and effective method for the control of HFC production and consumption. On the other hand, the countries that initially were not in favor of such an amendment used arguments such as HFCs are not ODS and that would be the reason why they could not be included in an international agreement established for controlling ODS use. In the discussions that took place over the years, other issues were presented as barriers for including HFCs under the Montreal Protocol, such as financial support for the developing countries, the commercial availability of HFC alternatives, technology transfer and many others.

After 9 years of intense discussions, the parties to the Montreal Protocol overcame the main obstacles for reaching a consensus decision[3], and in the 28th Meeting of the Parties on 15 October 2016 in Kigali, Rwanda, the parties decided on the addition of 17 HFCs to the Protocol (in a Group I). They are given with Global Warming Potentials using the IPCC AR4 report values (IPCC, 2007), in a new Annex F. The annex also presents the GWP of CFCs and HCFCs. It also includes HFC-23 (in a Group II), a chemical which mainly originates as a by-product in HCFC-22 production facilities.

HFCs therefore became controlled substances under the Montreal Protocol, with specific HFC control schedules adopted for developing and developed countries (parties). Developed (n-A5) countries will start to phase down HFCs by 2019. Developing countries (A5) will follow with a freeze of HFC consumption levels in 2024, with some countries freezing consumption in 2028.

The Kigali Amendment will enter into force on 1 January 2019, provided that it has been ratified by at least 20 Parties to the Montreal Protocol (or 90 days after ratification by the 20th Party, whichever is later).

2. Overview of the Kigali Amendment

The GWP values in the new Annex F must be used for the conversion of HFC mass quantities in in carbon dioxide equivalent ($CO_{2\text{-eq}}$) in all the reports countries need to present related to HFC phase-down implementation.

Including HFCs under the Montreal Protocol as controlled substances, will not affect the obligations the countries have under the United Nations Framework Convention on Climate Change (UNFCCC). The amendment will not have the effect to exempt Parties of their commitments to send to UNFCC HFC emissions inventory reports (as

---

[1] The Montreal Protocol decisions, as in other international agreements, are made based on a consensual manner not having vote and decision take by the majority

established in Articles 4 and 12 of the UNFCCC), regarding. HFC consumption and production will be controlled under the Montreal Protocol while HFC emissions will continue to be reported under the UNFCCC.

The Kigali amendment has different years for HFC consumption used in the baseline and various phase-down schedules, i.e., two for two groups of Article 5 Parties (developing countries) and two for two groups of non-Article 5 Parties (developed countries).

The reason for including both HFCs and a percentage of HCFCs in the baseline calculation is due to the fact that HFCs are thought to be utilized as alternatives for a certain portion of HCFCs still to be phased out. The HCFC component in the calculation is assumed to take this portion into account in the baseline.

In the reporting under the Montreal Protocol, the information about production, consumption, imports, exports and emissions of HFCs shall be expressed in $CO_{2\text{-eq}}$ and not in HFC mass quantities.

3. Potential Impact to Refrigerant Choice

The Kigali amendment has reinforced the momentum towards applications using low-GWP refrigerants and accelerates innovation for sustainable RACHP technologies. One of the key issues for the Kigali amendment implementation is the replacement of HCFC-22 and high-GWP HFCs with low-GWP refrigerants

Considering the R-410A and HCFC-22 replacement, the list of alternatives includes single-component or pure refrigerants, such as HFC-32, HC-290, HC-1270, R-717, R-744, and new blended refrigerants. These blends include the so-called hydrofluoroolefin (HFOs), unsaturated HFCs, such as HFO-1234yf and HFO-1234ze (E), along with traditional (saturated) HFC refrigerants to achieve the desired attributes of the blend, e.g., low-GWP, lower flammability, or lubricant compatibility. (UNEP, 2016).

In the last 3 years about 80 fluids, most of them blends containing HFOs, have been proposed for testing or are being tested in industry programmes, are pending publication, or have been published in ISO 817 and ASHRAE 34 refrigerant standards since the 2014 RTOC Assessment Report. The majority of these fluids are new mixtures (UNEP, 2016).

Considering the probability of the development of new molecules (pure refrigerants), it is important to mention that significant efforts have been done in the past to find new fluids. A recent study (McLinden, et al. 2015) started with a database of over 150 million chemicals, screening more than 56,000 small molecules and finding none of them ideal. It can be concluded from the study that the prospects of discovering new chemicals that would offer better performance than the fluids currently known are minimal.

Considering specific RACHP applications, the following aspects can be mentioned. HFC-32 is an alternative for use in a certain range of middle size air conditioners, and there is an opportunity for a much wider application of hydrocarbons as well as in larger capacity commercial refrigeration equipment. The issue of hydrocarbon flammability (A3 refrigerant) is very important and it will need to be addressed via a revision of standards. This now is an ongoing discussion inside the international standards technical committees. Once this flammability issue will have been adequately addressed in standards, it may lead to the acceptance of larger quantities in equipment than possible at present. There is a recent European Commission report (EC, 2016) on barriers posed by codes, standards and legislation to using climate-friendly technologies in the refrigeration, air conditioning, heat pumps and foam sectors.

In case of mobile air conditioning systems (MACs), a certain percentage portion may use R-744 (carbon dioxide), however, the majority is expected to use HFO-1234yf. For chillers, two pure HFOs, HFO-1234ze and HFO-1233zd, already commercialized, are now applied in larger chiller equipment.

Natural refrigerants such as R-744 are increasingly being used in supermarket systems worldwide – both in cascaded systems (R-744 for low temperature cascaded with a second refrigerant such as HFC-134a or similar and R-717 in limited cases) and in transcritical systems. Transcritical systems are being researched extensively to reduce their energy penalty at high ambient conditions through the use of component and system technologies such as ejector, adiabatic condensing, sub-cooling and parallel compression (UNEP, 2016). In lower ambient temperatures transcritical systems offer advantages associated with heat recovery and reuse in an adjacent heating/ hot water scheme. There are already some supermarket refrigeration systems installed in the field using these technologies.

The refrigerant selections that can be expected in the near future will be very much related to the perceived longer term "certainty" of low-GWP refrigerants, where the commercial availability, costs, energy efficiency, safety and servicing aspects will all be important. At present the choice is likely to be between the natural fluids (ammonia, CO_2, hydrocarbons) in equipment developed for their use and more expensive synthetic fluids (HFO, HCFO, HFC/HFO blends) in the types of equipment as used for HCFCs and HFCs. Considering the HFC/HFO blends the question is whether they will be restricted to equipment where no major redesign is being planned, or will also be applied in newly re-engineered designs. It is likely that there can and will only be a very limited amount of HFC-HFO blends in future (Kuijpers, 2017).

It is important to emphasize that the refrigeration, air conditioning and heat pump industry and refrigerant servicing sector cannot be assumed to cope with the large number of HFC/HFO blends.

4. Concluding Remarks

The adoption of the Kigali Amendment has reinforced the momentum towards applications using low-GWP refrigerants and is expected to accelerate innovation for sustainable RACHP technologies. Some HFC-free technologies face barriers to widespread uptake due to restrictive technical standards, in particular for flammable refrigerants. In order to enable transitions to flammable low-GWP refrigerants, a revision of the standard charge limits currently used is on the way.

The low GWP argument only cannot be expected to be the determining factor whether certain fluids will be considered. Energy efficiency, or rather, energy consumption reduction will be important. This is not only related to refrigerant thermo-physical

properties, it is also determined by equipment design, system configuration, component efficiencies, operating conditions, system capacity, and system hardware.
The choice for refrigerants is very likely to be a combination of energy efficiency, costs, and environmental performance including safety aspects associated with refrigerant toxicity and flammability. Regional and national regulations (e.g. flammability and charge) will drive many developments that will take place.
The use of pure refrigerants, i.e., HFOs and non-synthetic "natural" refrigerants, including hydrocarbons, can reasonably be assumed to expand widely after 2019-2020, and this in a substantial amount of applications in various RACHP subsectors. It can already now be observed that there is a remarkably high level of activity in the RACHP equipment development sector, which is also evidence to the commitment of companies engaged in this research and development to finding useful long term solutions in a market of ever-changing goals and objectives. As a result, the emphasis on equipment with improved energy efficiency (i.e., lower energy consumption levels) and refrigerants with a low-GWP is much more significant than before.
Both types of refrigerants, natural and synthetic, can and will co-exist in a near future, and can be complementary.

5. References

IPCC, 2007. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007*. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Kuijpers, L, 2017. *HFC phase-down schedules under the "Kigali" amended Montreal Protocol; potential impacts to the choice of alternatives*. Ammonia and CO2 Refrigeration Technologies, 2017, Ohrid, Republic of Macedonia, IIR Commission B2 with B1 and D1.

McLinden, M. O., Kazakov, A. F., Brown, J. S. & Domanski, P. A. , 2015. Hitting the bounds of chemistry: *Limits and tradeoffs for low-GWP refrigerants*. 24th Int. Congress of Refrig. Yokohama, Japan.

UNEP, 2016. *Decision XXVII/4 Task Force Report – Further Information on Alternatives to ozone Depleting Substances*. Nairobi, Ozone Secretariat

UNEP, 2017. *The Kigali Amendment to the Montreal Protocol: HFC Phase-down*. Retrieved online at: http://www.unep.fr/ozonaction/information/mmcfiles/7809-e-Factsheet_Kigali_Amendment_to_MP.pdf

Velders, G.J.M., Ravishankara A. R., Miller M. K., Molina M. Alcamo J., J., Daniel J. S., Fahey D. W., Montzka S. A., Reimann S., 2012. *Preserving Montreal Protocol Climate Benefits by Limiting HFCs*. Vol 335 Science. Retrieved at: www.sciencemag.org. *Published by AAAS*

Velders, G.J.M., Andersen S. O., Daniel J. D., Fahey D. W., McFarland M., 2007. *The importance of the Montreal Protocol in protecting climate*. PNAS 2007 104 (12) 4771-4772; doi:10.1073/iti.1207104

Velders G. J. M., Solomon S., Daniel, J. S., 2014. *Growth of climate change commitments from HFC banks and emissions*. Atmos. Chem. Phys., 14, 4563–4572,

EC 2016. *Report on the Barriers posed by codes, standards and legislation to using climate-friendly technologies in the refrigeration, air conditioning, heat pumps and foam sectors*. Retrieved online at: http://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/COM-2016-749-F1-EN-MAIN-PART-1.PDF