Refrigerants for a Sustainable Future

Subjects: Engineering, Manufacturing

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Worldwide use of high global warming potential (GWP) hydrofluorocarbon (HFC) refrigerants for space conditioning and food storage results in significant equivalent greenhouse gas (GHG) emissions. This is further exacerbated in developed countries by the current transition from hydrochlorofluorocarbon (HCFC) refrigerants to HFC refrigerants. Under the Kigali amendment to the Montreal Protocol, the proposed phase-out of currently used HFC and HCFC refrigerants has initiated a re-evaluation of some pre-existing refrigerants as well as the development and evaluation of new refrigerants. Making the ideal refrigerant selections for heating, ventilation, air-conditioning, and refrigeration (HVAC&R) applications is thereby difficult in an already overabundant refrigerants market. In this paper, a study of key parameters required of a good refrigerant is conducted, followed by the analysis of refrigerants desired and refrigerants used in two major sectors of the HVAC&R industry, namely commercial refrigeration and residential air-conditioning and heat pumps. Finally, keeping in consideration the global environmental regulations and safety standards, a recommendation of the most suitable refrigerants in both sectors has been made.

refrigerants thermodynamics global warming potential natural refrigerants hydrocarbons refrigerant blends

In 2015, the 21st session of the United Nations Framework Convention on Climate Change (COP21) convened in Paris, aiming to limit global temperature increase to 2 °C (Paris Agreement: 2016). Considering that the reduction in the use of high global warming potential (GWP) refrigerants is crucial to achieving this goal, the Kigali amendment to the Montreal Protocol was subsequently adopted during the 28th Meeting of the Parties held in October 2016 [1]. Under the Kigali amendment, a legally binding mandate for phasing out the production and use of hydrofluorocarbon (HFC) refrigerants was agreed upon to avoid 70 billion metric tons of carbon dioxide equivalent emissions cumulatively through 2050. According to the agreement, the phase down of HFCs begins on 1 January 2019 for developed countries (non-Article 5 countries), and for developing countries (Article 5 countries), the phase down begins on 1 January 2024. A summary of the phase-down schedule of HFC refrigerants dictated by the Kigali amendment is given in **Table 1**.

Table 1. HFC refrigerant phase-down per the Kigali amendment to the Montreal Protocol.

	Non-Article 5, Group 1 [a]	Non-Article 5, Group 2 [b]	Article 5, Group 1 [c]	Article 5, Group 2 [d]
Baseline years	2011, 2012, 2013	2011, 2012, 2013	2020, 2021, 2022	2024, 2025, 2026

	Non-Article 5, Group 1 [a]	Non-Article 5, Group 2 [b]	Article 5, Group 1 [c]	Article 5, Group 2 [d]
Baseline Calculation	Average production/consumption of HFCs in 2011, 2012, 2013, plus 15% of HCFC baseline production/consumption	Average production/consumption of HFCs in 2011, 2012, 2013, plus 25% of HCFC baseline production/consumption	Average production/consumption of HFCs in 2020, 2021, 2022, plus 65% of HCFC baseline production/consumption	Average production/consumption of HFCs in 2024, 2025, 2026, plus 65% of HCFC baseline production/consumption
Reduction Steps				
Step 1	2019, 10%	2020, 5%	2029, 10%	2032, 10%
Step 2	2024, 40%	2025, 35%	2035, 30%	2037, 20%
Step 3	2029, 70%	2029, 70%	2040, 50%	2042, 30%
Step 4	2034, 80%	2034, 80%	2045, 80%	2047, 85%
Step 5	2036, 85%	2036, 85%		

stry, the pursuit for the ideal refrigerant has been an ongoing challenge. The primary refrigerant selection criteria used during the initial years of the industry was *whatever works*; however, with advancements in technology and increasing environmental awareness, the refrigerant selection criteria have been modified to include not only energy efficiency but also *zero ozone depletion potential* (ODP) and recently *low global warming potential*. As a result, several alternative low-GWP refrigerants have been proposed for various HVAC&R applications, including natural refrigerants such as carbon dioxide (CO_2), ammonia (NH_3), and propane, as well as synthetic refrigerants such as R-1234yf and R-1234ze(E). However, these refrigerants have drawbacks, such as high pressure, flammability, and toxicity. In this paper, the pros and cons of potential alternative refrigerants will be studied, and these alternatives will be rated with respect to the current refrigerants used in several HVAC&R applications. The critical parameters used for the selection of the best refrigerant for an application will be discussed.

[a] Non-Article 5, Group 1: Non-Article 5 countries, excluding those in Group 2 (45 countries). [b] Non-Article 5, Group 2: Belarus, the Russian Federation, Kazakhstan, Tajikistan, and Uzbekistan. [c] Article 5, Group 1: Article 5 countries, excluding those in Group 2 (137 countries). [d] Article 5, Group 2: Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates.

Since energy efficiency is also key to achieving reduced global warming, the thermodynamic properties and performance of refrigerants are important parameters to consider. Furthermore, thermophysical properties of a refrigerant also dictate refrigeration system component sizing and required piping strength. The selection of refrigerants is also dependent upon the application. For example, in centralized refrigeration systems, a low operating temperature (−40 °C) and high refrigerant charge require the use of refrigerants with low normal boiling points and no flammability. However, flammable refrigerants may be permissible for use in small air-conditioning and refrigeration systems, such as window air conditioners and self-contained commercial display cabinets, due to their low refrigerant charge requirement. Toxicity is another major parameter to consider for indoor applications, where refrigerant may come into contact with occupants, but not necessarily for remote and industrial applications. In the following sections, the history of refrigerants and the characteristics of an ideal refrigerant are discussed, followed by an analysis of refrigerant options for the commercial refrigeration and air-conditioning sectors.

References

1. Heath, E.A. Amendment to the Montreal protocol on substances that deplete the ozone layer (Kigali amendment). Int. Leg. Mater. 2017, 56, 193–205.