

Sustainable Technologies for Air-Conditioning Workshop

Workshop Summary

Introduction

The Sustainable Technologies for Air Conditioning Workshop is the sixth in a series of workshops developed by the HFC Initiative of the Climate and Clean Air Coalition's (CCAC), in collaboration with other Partners, to provide information on advances in alternatives for different fields of application where HFC use is growing. The workshop was the second one to focus exclusively on alternatives in the air conditioning sector, one of the largest sectors currently using high-GWP HFCs and HCFCs. In partnership with the CCAC, the Alliance for Responsible Atmospheric Policy, as well as the governments of Canada, Germany and the United States of America provided in-kind and/or financial support for the workshop.

Held on the margins of the 29th Meeting of the Parties to the Montreal Protocol (November 20–24, 2017) in Montreal, Canada, the workshop was attended by more than 230 experts and representatives from governments, non-governmental organizations, and the private sector.

Nearly 30 international experts from developed and developing countries presented on the latest advancements in key HFC alternative technologies for the air conditioning sector, and topics related to safety, operation performance in many environments (including high ambient temperatures), energy efficiency, and technology deployment.

The workshop was organized into five sessions of presentations and panel discussions:

- Session I – Overview and General Aspects of Air Conditioning, with presentations by Steven Yurek of the Heating and Refrigeration Institute (AHRI) and Lambert Kuijpers of the Refrigeration Technical Options Committee (RTOC).
- Session II – Energy Efficiency Considerations in the Air Conditioning Sector, with presentations and panel discussion from Walid Chakroun of ASHRAE and Kuwait University, Andrea Voigt of EPEE, and Dick Lord of UTC Controls and Security. The Session was moderated by Leslie Smith from the National Ozone Unit of the Ministry of Finance and Energy of Grenada.
- Session IIIA – Low GWP Alternatives for Residential and Light Commercial Applications, with presentations and panel discussion from Dr. R.S. Agarwal of India, Brian Fricke of Oak Ridge National Laboratory, Ole Nielsen from UNIDO, Mary-Ellen Foley from the World Bank, Charlotte Skidmore from AHAM. The Session was moderated by Marc Chasserot from Shecco.
- Session IIIB – Large Building/Commercial Air Conditioning, with presentations and panel discussion from Gerrit Kerkenpass from Frigoteam Germany, Mike Thompson from Ingersoll Rand, Carson Gemmil from Enwave Canada, Paul de Larminat from Johnson Controls, and Ann-Sophie Hamel-Boisvert from Carnot. The session was moderated by Samuel Yana Motta from Honeywell.

- Session IV – Mobile Air Conditioning for Light Vehicles, with presentations and panel discussion from Mary Koban of Chemours, Stefan Elbel of the University of Illinois and Creative Thermal Solutions, and Sangeet H. Kapoor of Tata Motors. The session was moderated by Daniel de Graaf of the German Environment Agency.
- Session V – Opportunities, Challenges, and Experiences with Transitioning to Low-GWP Alternatives, with presentations and panel discussion from Ayman Eltalouny of UNEP, Ole Nielsen of UNIDO, Cornelius Rhein, European Commission, Martin Sirois, Environment and Climate Change Canada, Gildardo Yañez, Mexico, Tetsuji Okada, President, Japan Refrigeration and Air Conditioning Industry Association, and Bassam El Assad, Refrigeration Technical Options Committee (RTOC). The session was moderated by Shamila Nair-Bedouelle, UNEP OzonAction

Summary of presentations

Session 1 Overview and General Aspects of Air Conditioning

Air Conditioning Sector – Overview and Trends

Stephen Yurek, Air Conditioning Heating and Refrigeration Institute (AHRI)

With the global phase down of high-GWP HFCs just beginning, big changes are coming for the refrigeration and air conditioning industries. These changes are driven by the 2016 Kigali Amendment as well as national regulation in Europe, US, Canada, Japan, and Australia. The three main challenges facing the phase down are:

1. Regulatory and safety barriers must be adapted to allow the safe use of equipment using A2L (mildly flammable) and A3 (highly flammable) refrigerants in homes and buildings;
2. Commercial availability of alternative refrigerants and equipment;
3. Knowledge limitations among distributors, technicians, engineers, building owners, and consumers about new technologies.

The issue of safety standards must be addressed quickly so as to not create a barrier for the phase down. Industry sectors and countries are already beginning to move to alternative refrigerants where safety standards and technologies are in place. In the US, safety standards are used to set model building codes and equipment standards, all of which take time to amend once the new standards are in place. Once new model building codes are in place, cities and states will need to adopt them. This process may not be complete until 2021 or 2022 and if delayed could represent a significant barrier to the phase down. This is why the Heating and Refrigeration Institute (AHRI) with the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), California Air Resources Board (CARB), and others are conducting research on the safe use of alternatives which will be complete in the first quarter of 2018 and be provided to all code-making bodies.

Addressing commercial availability of alternatives requires understanding that all components for new technologies must also be available. This requires testing for all components and specific training for installation and maintenance technicians.

Training is particularly important because many alternatives are flammable or mildly flammable. The Global Refrigerant Management Initiative (GRMI) is currently working to collect best practices for refrigerant management and AHRI is working with UNEP to develop training programs.

Article 5 (A5) countries are just now beginning to phase out HCFCs and this presents an opportunity to leapfrog past HFC to low-GWP alternatives, but this can only be achieved if we work together in a deliberate way to overcome these barriers.

Overview of Refrigerant Alternatives in the Air Conditioning Sector

Lambert Kuijpers, Refrigeration Technical Options Committee (RTOC)

Traditionally, HCFC-22 and HFC-134a have been the two primary pure refrigerants used for the air conditioning sector along with two HFC blends: R-410A and 407C, although a number of new blends have emerged in recent years. The number of medium- and low-GWP pure fluids and blends in commercially available equipment is still very limited. A total of 106 medium to low-GWP alternatives have been identified for the air conditioning sector with GWPs of less than 1000. From this list about 30 identified alternatives have GWPs of less than 300 and ‘reasonable’ evaporative pressures. Only 7 fluorocarbon alternatives have GWPs of less than 150, and these are all HFO blends.

Currently 100 million pieces of air conditioning equipment are produced every year and 1.4 billion currently in operation globally (see Figure 1). All major types of AC units have a number of potential alternatives but choosing an appropriate alternative is often a delicate choice. The use of pure refrigerants such as low- or medium-GWP HFCs and ‘natural’ refrigerants is definitely going to expand. In the future there are likely to be only a limited number of HFOs commonly used. HFO-1234yf is one example of a pure fluid that will be applied in MACs. HFO-1234ze and -1234zd probably only have a future in chillers.

Many manufacturers logically want one clear option, but chemical manufactures are now coming forward with an ever-growing string of mixtures. HFC/HFO blends can be a good solution for the ‘low-GWP issue,’ but an ever-growing number of blends may cause the manufacturing industry to adopt a ‘wait and see’ attitude. The servicing sector also cannot cope with a huge number of blends, which makes a smaller number (perhaps 3-5) of commercialized blends desirable.

A/C Type	Equipment				Refrigerant	
	Produced annually (million)	non-Article5	Article5	Units in Operation (million)	Current	Options
Small self-contained	17	50%	50%	200	R22, R410A, R407C, R290	R290, R32, R444B, R446A, R447A, etc.
Split non-ducted (residential & commercial)	70	20%	80%	1000	R22, R410A, R407C, R290, R32	R290, R32, R444B, R446A, R447A, etc.

Split-ducted (residential & commercial)	11	33%	67%	150	R22, R410A, R407C, R744	R744, R32, R444B, R446A, R447A, R290, etc.
Multi-split (residential & commercial)	1.2	25%	75%	7	R22, R410A, R407C	R32, R444B, R446A, R447A, R290, etc.
Ducted commercial packaged	1 million	33%	67%	20	R22, R123, R410A, R407C, R290, R1270, R744, R717, R1233zd, R1234ze	R717, R744, R290, R1270, R1234ze, R1233zd, R1234yf, R32, R444B, R446A, R447A, etc.

Figure 1 – adapted L. Kuijpers presentation slides

Since many alternative refrigerants are either flammable (A3) or mildly flammable (A2L), establishing appropriate standards for safe equipment use and maintenance is critical for ensuring market availability. Working Group 16 of the International Electrotechnical Commissions (IEC) started working on new standards for A2 and A3 refrigerant maintenance in 2015. It could take up to 2021 to finalize the standards and even longer before they are adopted in national standards.

To move forward quickly, it is important to reduce refrigerant charge size. The smaller the charge size the more you can safely use A2L and A3 refrigerants in larger equipment.

In conclusion, the Kigali Amendment has reinforced the momentum towards low-GWP refrigerants, but regional and national regulations will have a significant impact on refrigerant and technology choice. Adequately addressing issues surrounding flammability and equipment standards are critical for ensuring market availability of alternatives. Ultimately, all stakeholders have the objective of finding an alternative with negligible GWP whether via a step-change or a gradual shift. In the medium-term, we will likely see choices made based on a combination of equipment energy efficiency, cost/price levels, together with good environmental performance, as well as safety and servicing considerations.

Q&A

Which of the blends are relevant to heat pumps?

Unlike cooler systems, heat pump systems are increasingly using hydrocarbon (HC) and CO₂.

Session 2 Energy Considerations in the Air Conditioning Sector

Energy Efficiency in Air Conditioning Sector

Walid Chakroun, Kuwait University

There are a number of factors that go into choosing a sustainable refrigerant: impact on the stratospheric ozone and climate; its flammability, toxicity and other safety concerns; the properties of energy performance; and, costs. The phase-down of high-GWP HFCs under the Kigali Amendment presents an opportunity to select sustainable alternative refrigerants that improve on many of these factors, particularly energy efficiency. The Kigali Cooling Efficiency Program (K-CEP) was created through US\$52 million in grants from 18 philanthropist organizations for a fast-start in developing countries to expand energy efficiency while phasing down HFCs.

Currently, 15% of global energy consumption per capita is for cooling and demand for cooling is expected to grow 7% per year until 2050. On a CO₂ equivalent basis, as much as 80% of the GHG emissions from air conditioning (AC) are a result of indirect emissions from energy use, and the best current RAC equipment is operating at around 50-60% of the theoretical maximum energy efficiency. Maximizing energy efficiency gains during the HFC phase-down is vital for the success of the Montreal Protocol and climate mitigation.

The AC industry faces a number of challenges when selecting sustainable alternative refrigerants that will need to be overcome to maximize the sustainable benefits of the HFC phase-down. Currently the majority of commercially available household AC technologies in Article 5 (A5) countries relies on high-GWP refrigerants and perform less efficiently in high ambient conditions. Many alternatives are still being studied for compatibility with existing systems and suitability in new environments, particularly those with high ambient conditions. Many industry players still need to test and build a basic understanding of the properties of alternatives such as burn velocity, compatibility with lubricants, issues with other system materials and components, and energy efficiency. These tests must be done in a systematic way so that they are all comparing apples to apples. In many cases testing standards and codes still do not exist since alternative refrigerants are still being investigated. Refrigerant manufacturers are reporting data on energy efficiency, but this needs to be independently verified. Once sustainable alternatives are selected, new safety codes are often required to ensure the safe use of the refrigerants, as well as training and certification for installation and repair technicians.

Realizing the full potential of new refrigerants also often requires a full system re-design to make sure that we are gaining the maximum potential energy efficiency from the refrigerant and the equipment. This requires ensuring that the most efficient technologies are available to manufacturers during the transition. Large-scale AC manufacturing is limited to a few countries, but they often depend upon components developed in other countries. This increases the focus on strong technology transfer. In the coming decades, technological innovation is expected to improve performance to approximately 70-80% of the theoretical energy efficiency limit for room air conditioning (RAC).

To maximize energy efficiency gains, the Montreal Protocol and countries should: support testing and application of Not-In-Kind (NIK) technologies that are still in the R&D stage and study the energy efficiency of such systems; support improvement of RAC components such as compressors, heat exchangers and control systems; support opportunities to reduce cooling demand by e.g. improving building envelopes; support the introduction of Minimum Energy Performance Standards (MEPS) in developing countries that do not have them while strengthening currently existing MEPS.

Energy Efficiency and Its Role in the EU

Andrea Voigt, European Partnership for Energy and the Environment (EPEE)

Improving energy efficiency will play an extremely important role in achieving the temperature goals of the Paris Agreement. Without significant improvements in energy efficiency economy-wide, paired with a rapid transition to renewable energy we will not be able to achieve our goals. The EU has committed to reduce GHG emissions by 40% by 2030 (compared to 1990 levels). The non-binding Clean Energy Package aims to make the EU a world leader in energy efficiency and renewables by increasing the share of renewable energy to 27% and increasing energy efficiency by 27%. The EU Energy Performance Building Directive (EPBD), Ecodesign Directive, and Energy Labelling Regulations are key drivers of the energy efficiency program.

The EPBD supports renovation of existing building stocks, particularly for heating and cooling equipment. Currently heating and cooling represents 50% of annual energy consumption in the EU. Energy efficiency measures such as targeted renovation, passive house technologies for new buildings and replacement of fossil fuels for heating, cooling and cooking with electricity from renewables could reduce energy consumption for heating and cooking by 10% and reduce total emissions by around 90% by 2050.

The Ecodesign Directive is the EU's version of MEPS and is based on a Least Life-cycle Cost calculation which balances life-cycle cost with energy efficiency. In the framework of the Directive, minimum energy efficiency standards are established product-specific regulations and if the product does not meet the standard it is prohibited to enter the EU market. There are a number of regulations already in place in the heating, ventilation, air conditioning and refrigeration (HVACR) sectors such as one for AC units less than 12 kW (Commission Regulation (EU) No 206/2012), which is currently under review. The Ecodesign Directive has already produced annual energy savings equivalent to the energy consumption of Italy and produced savings of 500 Euro per year per household.

Moving forward the Directive needs to continue establishing technically neutral standards that give manufacturers the freedom to design new products and innovate.

The Ecodesign Directive also has a number of measurements in the HVACR sectors (e.g. measures on small equipment below and above 12 kW), which will drive market transitions. Several sectors are key to success such as affordable products and technically neutral MEPS for design freedom. In conclusion, the balance between products and buildings is the key to improve energy efficiency and have more renewable energies.

Options and Opportunities for Improving Energy Efficiency of Air Conditioning and Refrigeration

Richard Lord, United Technologies

In the United States, buildings use 65% of all electricity and account for 40% of total energy use. Heating, ventilation, air conditioning and refrigeration (HVACR) as well as water heating accounts for approximately 45% of total energy consumption in commercial buildings. Globally about 80% of total greenhouse gas emissions from HVACR are from indirect emissions from power generation (fossil fuel combustion) to run the equipment. This is why, for overall environmental improvements, efficiency is a very important area to focus on and must be improved along with improvements in direct emissions from refrigerants used in HVAC&R equipment.

There are a number of methods for catalyzing improvements in energy efficiency such as establishing component efficiency standards, prescriptive equipment and design requirements, subsystem approaches, full building approaches, and outcome-based approaches. Many MEPS regulate specific components, like the rooftop or the fans, which begins to take up a lot of time and effort for research and development. We are starting to reach the technical limits of the current appliance component approach to energy efficiency improvements, whereas building-wide or outcome-based standards are more flexible and better for supporting innovation. Focusing on establishing standards for individual components can cause shifts in the selection of equipment for a building which may not be ideal from a whole-system perspective. The ASHRAE 90.1 New Construction Commercial Efficiency Requirements, implemented in 1989, is an example of a full building efficiency standard that has catalyzed major improvements in energy efficiency.

It is also important to understand what drives improvements in energy efficiency. We often use metrics for energy efficiency that are not well aligned with the reality of building operations. Most systems spend very little time, if any, at full load, which is where current component efficiency regulations and standards are focused. Building loads vary significantly by building type and air movement energy and ventilation air conditioning are a major part of the building energy, but not a focus of most component efficiency metrics.

Temperature zones is another important consideration for energy efficiency. ASHRAE recently expanded the 17 standard climate zones to 19, remapped all cities to the new zones and developed a global climate zone map. The ASHRAE 90.1 program has developed 19 benchmark cities for each of the 19 climate zones, which provide new concepts in building designs and standard development.

In summary, if we change our approach and focus on higher-level requirements and not component and prescriptive design solutions, this will enable the industry to consider new and innovative solutions using concepts like hybrid systems, energy recovery, renewable energy and controls to make significant improvements in overall building and building complex energy use.

Q&A

What is the main consideration of energy efficiency regarding to building?

The main consideration is to design the building as a system by the collaboration of architects and engineers. The specific design relates to country and regions is also important.

A5 countries typically do not have MEPS or other methods in place. What are some key lessons or considerations for A5 countries considering establishing MEPS?

In terms of MEPS, the experiences of implementation in EU could be applied to A5 countries. One of the key lessons of MEPS is that that should always remain technically neutral and have less limitations to ensure innovation and design freedom to manufacturers.

Session 3A Low GWP Alternatives for Residential and Light Commercial Applications

Sustainable Technologies for Air-Conditioning Sector

Radhey S. Agarwal, India

Rapidly growing demand for AC in Article 5 countries coupled with global commitments to stabilize global temperatures, and a growing emphasis on enhanced performance requirements is driving the search for sustainable technologies in the AC sector. In the Indian context, a MEPS standard was established for buildings and appliance energy labelling program. The building stock in India is increasing rapidly, bringing challenges in terms of meeting AC demands in the future and meeting building energy efficiency standards. AC is energy intensive, accounting for 40% of total electricity consumption in India. Improving energy efficiency and converting to low-GWP technologies are necessary but may not be sufficient to sustain the growing AC demand in India. These must be paired with cooling load reductions through better building envelope design, optimizing indoor temperatures, reducing other internal loads such as lighting, and changes in patterns of use. For example, in India, there are new building designs with more advantage of sunlight to reduce cooling load substantially. Many Indian cities are also planning on using district cooling.

Q&A

What refrigerants are used for district cooling in India?

There are many choices of refrigerants for district cooling in India. Since the system can be designed far away from the area of use, toxic or flammable refrigerants are viable options.

What measures are there to help cut down cost for domestic AC?

The cost of domestic AC is growing up in each unit, but only in the order of 10-15%. Therefore, as the number of manufacturing units grows, the costs are always balanced.

Evaluation of Low-GWP Refrigerants for the AC Sector

Brain A. Fricke, Oak Ridge National Laboratory

Identifying the ideal refrigerant is a never-ending challenge due to the necessary tradeoffs between the relative characteristics of all refrigerants and uses. There are currently two broad categories of next-generation refrigerants to replace high-GWP HFCs: hydrofluoro-olefins (HFOs) and natural refrigerants (i.e. CO₂, hydrocarbons, ammonia). Of these existing alternatives, there are a few non-flammable options that are acceptable in all AC equipment, but they also generally have higher GWPs. There are a larger number of mildly-flammable options, which generally have lower GWPs, but their flammability can limit their broad usage.

The Oak Ridge National Laboratory has conducted evaluations of R-410A alternative refrigerants in Mini Split and Rooftop AC systems. Among all tested refrigerants, only R-32 (GWP 677) achieved a better coefficient of performance (COP) and energy efficiency than R-410A in both standard and hot ambient temperature conditions. Many HFO refrigerant blends

achieved comparable efficiency to R-410A with a slightly higher COP and performed well in high ambient conditions. However, the flammability of many alternatives will limit the maximum safe refrigerant charge and require specific equipment design and guidelines for safe handling, servicing and transportation practices.

Q&A

How about R290?

R-290 is a good refrigerant with a safely designed system and is already widely applied in industry. Compared with other refrigerants, R-290 has a higher COP which is similar to R-22. However, the safety of R-290 is always a concern.

Did the tests use prototype units or units currently available in the market?

The tests were performed on commercially available equipment without any specific modifications. Of course, the results would be better if the equipment was optimized for one of the new refrigerants.

Conversions to HC in HPWH and RAC sectors in China

Ole Nielsen, United Nations Industrial Development Organization (UNIDO)

The conversion of China's window AC and mini-split systems began nearly a decade ago with their HPMP stage I (2011-2016) and support from the German Agency for International Cooperation (GIZ) and UNIDO. During the HPMP I period, 18 split lines were converted to R-290, 8 to R-410, and 3 compressor lines were converted to R-290 resulting in a total potential annual output of six million R-290 split AC systems. To address regulatory barriers for the use of R-290, the Chinese industry and government have been active and have created a new working group to look at safety standards for flammable (A3) refrigerants as well as options for limiting refrigerant charge sizes and how to handle larger AC systems.

Through the implementation of HPMP I, issues related to production safety when converting from a non-flammable to a flammable refrigerant have been largely resolved. There are only five operations in a manufacturing assembly line that need to be changed to work with a flammable refrigerant. These locations require new equipment for leak protection and some change in operations. A new process also needs to be established to move leaking equipment to a safe environment.

China's HMPM stage II was approved in 2016, is even more ambitious than stage I and will focus on additional conversions to R-290 as well as 2 CO₂ conversion for heat pumps.

Looking to the future, the use of R-290 in the RAC sector is promising. There are concerns about flammability, but these are manageable, particularly in smaller equipment. China has developed substantial know-how on how to safely manufacture R-290 systems.

Q&A

What is the average cost for modifying existing production lines to handle an A2L refrigerant?

The cost to convert a line to mildly-flammable (A2L) refrigerant is about 1 million USD.

Introduction of Alternative Refrigerant in the Thailand Air Conditioning Sector

Mary-Ellen Foley, World Bank Group

Thailand is the second largest manufacturing base for residential air conditioning in East Asia, producing 16 million units per year, and is a major export hub. In 2012 the refrigeration and air conditioning industry was dominated by HCFC-22. Air conditioning manufacturing made up 43% of HCFC consumption and so Thailand did not have a choice but to quickly address manufacturing consumption in this sector as well as downstream servicing. While HFC-410A was an available alternative for R-22, the Thai industry was concerned that major export markets in the EU would close if they switched to R-410a and wanted to explore other lower-GWP options. After weighing options, the industry decided to move to R-32 technology, which is manufactured by Daikin, but had a number of concerns such as access to patents, refrigerant costs, and the lack of local technical expertise to safely use the new refrigerant.

Daikin agreed to allow developing countries to freely access 93 basic application patents for R-32 as a means to encourage commercialization. The World Bank Group joined with Daikin to organize factory visits in Japan for Thai manufacturers to demonstrate equipment installation and safety measures. Daikin also agreed to provide tailored support to Thai manufacturers to improve AC quality.

The World Bank Group also worked with Thai authorities to study safety issues related to the use of R-32. Based on tests and evidence, Thailand's Department of Public Works modified its regulations to allow for the installation of split-type AC using R-32 with a capacity of up to 53,000 Btu/hr in high-rise buildings.

As a result of this cooperation, the first R-32 AC system manufactured by multinationals was introduced in Thailand in 2015. Three Thai manufacturers introduced R-32 models in 2016 and sold 30,000 units with a performance better or similar to the systems they replaced.

Developments and Future Directions for Residential Room Air Conditioning

Charlotte Skidmore, Association of Home Appliance Manufacturers (AHAM)

AHAM is a trade association representing manufacturers of major, portable and floor care home appliances in the US and Canada. For residential air conditioning products, most of the industry in North America has already begun transitioning to R-32 and there are other options being considered, but not all lower GWP refrigerants can be used for room and portable air conditioning.

There are only a handful of global manufacturers that produce room and portable air conditioners and dehumidifiers. These manufacturers would prefer to produce models that that can be distributed globally with few changes in refrigerants, but they need to consider how to meet local standards, energy efficiency requirements and environments. At this point there are no 'drop-in' solutions that manufacturers can turn to for residential room air conditioners and portable air conditioners.

Today, room and portable air conditioners are listed to UL Standards 484 and CSA C22.2 No. 177 or a harmonized Standards UL/CSA 60335-2-40, which all restrict how manufacturers use flammable refrigerants. To support updating the standards, AHAM has conducted joint

research on the use of mildly flammable (A2L) refrigerants to evaluate leak and ignition testing and has also published a guidance document on 'Safe Servicing of household Appliances with Flammable Refrigerants: Recommended Practices.' For the future these standards are planned to fully transition to harmonized standards.

For future development in the use of alternatives, many appliance industries have announced a voluntary agreement to phase down HFC in refrigeration products for refrigerant and foam blowing agents. The industry will stop using HFCs in compact household refrigeration products by 2021, full-sized household refrigeration products by 2022, and built-in household refrigeration products by 2023. The industry has already largely transitioned out of HFC foam blowing agents as less than 30% of products currently contain HFC foam blowing agents.

The California Air Resources Board (CARB) also announced its intent to publish a regulation to phase down HFCs. Although the US EPA does not have regulation on this topic currently, they would like to move forward with limiting the charge size and products to phase down HFCs and improve energy efficiency.

Q&A

What is the concern for HFOs leading to increased trifluoroacetic acid (TFA) formation?

A recent report from Beijing said the usage of HFO will lead to 17 times higher TFA pollution in the future, but more studies should be focused on the connections between HFO and TFA.

Session 3B: Large Buildings/Commercial Air Conditioning

Technical Basis and Application of Hydrocarbon Chillers in Germany

Gerrit Kerkenpass, Frigoteam

Frigoteam was founded in 1994 as refrigeration technology wholesaler. Since 2008, Frigoteam has focused exclusively on natural refrigerants, delivering the first ammonia chiller in 2008 and the first hydrocarbon chiller in 2011. Since 2008, Frigoteam has delivered 155 natural refrigerant-based chillers, 111 of them using hydrocarbons, with no massive leaks or accidents. Applications range from food industry and pharmaceutical industry to commercial and datacenter air conditioning.

HC-based chillers can be applied safely and efficiently for many uses. Limiting refrigerant charge, safely positioning chiller units in non-public areas, and designing the unit for the specific use and environment are important. Using only appropriately trained staff for commissioning and servicing also ensures safe usage.

The charge size limit lies at 25 kg and 5 kg of R-290 for outdoor and indoor installation, respectively. For bigger capacities, several refrigerant circuits are connected by the coolant (water) circuit, so that the maximum charge per circuit for indoor installation is not exceeded. This leads to a redundant multi circuit system which can compensate switching off one circuit for e.g. maintenance purposes.

Chiller Options and Energy Efficiency

Mike Thompson, Ingersoll Rand

Chillers are a market segment that is a little more advanced in terms of low-GWP alternatives than some other sectors. While a lot of investment has gone into research and development for alternatives, primarily from larger companies, the Kigali Amendment was an important final signal to the market for significant investment in the next generation of technologies, particularly for smaller companies with less resources for research and development.

The Kigali Amendment also provides opportunities to improve energy efficiency in chiller applications. Many manufacturers are redesigning chillers that use medium or low-pressure alternative refrigerants because they can get as much as 10% more efficiency than existing systems. Many solutions for chiller applications have been identified and are available in many markets, and industry is moving fast to bring the next generation of solutions to market.

Strong collaboration with local governments is critical to reduce barriers to bring next generation chillers to market. New refrigerant approval is critical. Each country often has its own approval process for new refrigerants with some taking as much as 20 years to complete. A consistent approval process for refrigerants around the world would lead to better, safer, and more cost-effective solutions.

Q&A

What is the experience and application for multi-splits in commercial AC market?

There is not much different for multi-splits for A/C commercial market from the residential even though the charges and safety concerns are larger.

District Energy in Toronto

Carson Gemmil, Enwave Canada

District energy is a centuries-old proven set of technologies for high efficiency cooling, heating and power in cities. Approximately two-thirds of the world's energy is consumed in cities, and they are responsible for over 70% of global CO₂ emissions, which makes district energy an important part of the solution for climate mitigation. Enwave manages a number of district energy projects in North America, such as the largest ice-making system in the world in Chicago, and a biomass district heating system in Seattle.

Enwave provides district heating and cooling for downtown Toronto using a deep lake water system. The system draws water from the deepest part of Lake Ontario, where the water temperature is a constant 4°C year-round. The deep lake water is run through a series of heat exchanges which absorb the heat from a closed-loop water-cooled system for downtown buildings. This system is an efficient example of a non-refrigerant district energy cooling system.

Over 50% of the installed capacity of the district cooling system is provided by the cold lake water which in turn reduces for overall GWP of the system. The district system, which also uses HFO chillers, has a capacity weighted overall GWP of 454 and ODP of 0. The low overall GWP of the district system supplies cooling requirements of a large number of buildings in the City of Toronto which would otherwise likely use higher GWP refrigerants if each building had their own cooling system. Customers include hospitals, hotels and entertainment complexes, data centers, commercial and residential properties.

The feasibility of this type of system is clearly dependent on the location and availability of a cold-water source but there are other large urban centres around the world that could take advantage of a deep lake district water system.

Q&A

Can a district cooling system run on sea water?

Yes, it is possible to run the cooling system on deep sea water but there are technological challenges that impact the economic feasibility of such systems. The technologies and materials do exist to run sea-water based systems and are likely to be applied on near-sea cities and hot places.

Chillers for High Ambient Conditions: What Technologies and Fluids

Paul de Larminat, Johnson Controls

Solutions exist for chillers in high ambient air temperature conditions but identifying appropriate options requires a systems approach that balances initial costs, installation, safety and energy consumption. Higher ambient temperatures mean that systems will

operate at a lower efficiency. Low pressure refrigerants tend to have a better life cycle efficiency but are often more expensive due to the need for higher volumetric flow.

In these conditions, the condenser technology used becomes very important for improving the efficiency of the refrigerant and controlling costs. If a sustainable supply of water is available, the system can rely on an evaporative tower which would make Riyadh no worse than Toronto for condensing energy consumption.

Condenser and cooling technologies are very important because they impact the evaluation of condensing temperature. Take water as an example, the dry reference temperature is not appropriate if an evaporative cooling tower is available. In terms of the safety issue, chillers are less susceptible to safety issues due to their inherently “indirect” system and because they are installed separately, but some alternatives are still flammable. Importantly, the safety must always be assessed very carefully. For heat exchange technologies, pure refrigerants work better than blends. Regarding alternatives, R-22 has no single replacement but flammable hydrocarbons and ammonia can be used when safety considerations are addressed. In conclusion, solutions for chillers exist even in hot climates, but higher ambient temperatures always lead to lower efficiency. The life cycle analysis for new technologies is especially important in HAT environments.

Air conditioning possibilities with Transcritical CO₂

Ann-Sophie Hamel-Boisvert, Carnot Refrigeration

Carnot’s work on transcritical CO₂ cooling systems began with supermarket refrigeration, grew into warehouse refrigeration and chillers and is now moving into AC. CO₂ is a strong option for AC systems that are not dependent upon external temperature conditions, such as data centers because it has good heat transfer performance which creates the possibility of ‘free-cooling’ during colder months. When the external temperature is lower than the evaporative temperature, CO₂ in the system reacts the same way that water reacts in the atmosphere. This allows the system to bypass the compressor and run completely on fans, significantly decreasing energy consumption. The efficiency of CO₂ as a refrigerant improves as temperatures increase and so it is important to analyze the year-long lifecycle efficiency of the system based on the cooling need and the external temperatures in a particular location. Since 2013 Carnot has replaced approximately 60 R-22 systems with CO₂ systems in data centers in Canada.

In 2017 the German Embassy in Ottawa converted to a CO₂ AC system. This project demonstrated the viability of a CO₂ system for air conditioning, even in a location that requires a relatively high design temperatures and humidity levels. One of the advantages of CO₂ systems is the heat recovery that can be leveraged in locations that may have needs for both cooling and heating at the same time during shoulder seasons. Another advantage of CO₂ systems is that it allows the compressor to be shut down when outside temperatures fall below 6-7 degrees Centigrade which in turn dramatically increases the overall energy efficiency of the system to a coefficient of performance above 25, much higher than conventional systems with operational compressors.

Carnot believes this technology will become more common in locations that can take advantage of the benefits of CO₂ systems.

Session 4: Mobile Air Conditioning for Light Vehicles

Opteon YF (HFO-1234yf) Overview

Mary Koban, Chemours

The Mobile Air Conditioning (MAC) sector is currently undergoing a transition to low-GWP alternative refrigerants. Prior to the passage of the Kigali Amendment, the main driver for this transition in the US was the 2016 EPA mandate for corporate fleets to achieve CO₂ equivalent emissions of less than 250 grams per mile. Similarly, in the EU the MAC Directive requires the use of refrigerants with a GWP of less than 150. There are a number of available options for replacing high GWP refrigerants in the MAC sector including HFO-1234yf, HFC-152a with a secondary loop system, and CO₂.

HFO-1234yf has a GWP of less than 1 and despite being mildly flammable, the best fit to directly replace the current industry standard of HFC-134a. HFO-1234yf has similar performance and operating characteristics to HFC-134a, is thermally stable under extreme use conditions in a MAC system and requires only modest design changes to the MAC system. This compared to a secondary loop system using HFC-152a (GWP 138) or a CO₂ system, both of which require additional equipment increasing costs and vehicle weight which impacts fuel economy.

The judgment of flammability depends on how hard it is to ignite and what happens when it does ignite. HFO-1234yf is classified as a mildly flammable (A2L) refrigerant but is both difficult to ignite and burns weakly if ignited. HFC-152a is a flammable (A2) refrigerant which is why it is recommended for use in secondary loop systems. HFO-1234yf is one of the least flammable products under the hood by this standard.

HFO-1234yf is already being safely used in MAC systems by all major vehicle manufacturers. In 2017 there were 40 million vehicles on the road with MAC systems using HFO-1234yf. Chemours is increasing its refrigerant manufacturing capacity to meet the growing demand for HFO-1234yf and expects to complete a new plant in Corpus Christi, Texas late in the third quarter of 2018. Compared with other refrigerants it has the best balance between flammability and climate impact.

Transcritical CO₂ for Mobile Air-conditioning and Heat Pump Systems

Prof. Stefan Elbel, University of Illinois at Urbana-Champaign

There are opportunities for the use of CO₂ as a refrigerant for mobile air conditioning (MAC) systems. Historically, CO₂ has been a popular refrigerant in many sectors, but requirements for high pressure equipment and additional costs for servicing and maintenance often made it uncompetitive when CFCs became available. Recent innovations in materials and technologies and concerns for the environmental impact of other refrigerants have improved the standing and competitiveness of CO₂ in MAC systems. While initial modelling indicated that CO₂ would perform poorly, prototype tests of CO₂ MAC systems have produced surprisingly good results. The test showed that CO₂ outperformed R-134a except during idle or ambient temperatures above 35° C.

Furthermore, the increased need for heat pump and combined AC/HP systems in electric and hybrid vehicles significantly advantages CO₂ systems. Due to higher pressures, CO₂ systems can cover a wider range of temperatures than R-134a or R-1234yf. Although CO₂ has many advantages, the path to successful implementation in market competitive MAC systems is long. For example, Daimler has developed a new CO₂ MAC system, but it is still very expensive.

For the past 75 years, mechanical engineers in the air conditioning industry were not well challenged because the chemical engineers were able to provide refrigerants which allowed for simple refrigerant cycles. Now that we are beginning to transition away from manufactured refrigerants, the mechanical engineers will have a lot of work to do and we should expect new systems that could allow CO₂ to be the 'final' refrigerant for many applications. There are technologies that will allow CO₂ to work at higher temperatures and as markets mature prices will come down. Heat pumps for electric cars could bring a significant breakthrough for CO₂.

Secondary Loop Mobile Air Conditioning System

Sangeet Kapoor, TATA Motors Ltd.

The passage of the Kigali Amendment is significantly impacting the mobile air conditioning (MAC) industry. Global automakers are already abandoning MAC systems using HFC-134a and are looking for the most affordable options that deliver highest energy efficiency with the lowest carbon footprint. Vehicle purchasers/owners prioritize lower purchasing costs, lower servicing costs, fuel saving advantages of deceleration cooling and powered cooling at high engine efficiency. This is why secondary loop MAC systems are a favourable option for both vehicle manufactures and owners.

There are currently three refrigerants approved by the US EPA Significant New Alternatives Policy (SNAP) program and also satisfy the EU F-Gas Directive (GWP<150) for MAC systems: HFC-1234yf, CO₂, and HFC-152a. HFC-152a has a GWP of 138, operates at a higher efficiency than HFO-1234yf and CO₂, does not produce trifluoroacetic acid (TFA), and is not subject to a manufacturing patent. HFC-152a is mildly flammable, but automobile manufactures have significant experience designing equipment to safely handle other flammable fluids in vehicles such as the fuel, hydraulic fluid, motor oil, brake fluid, antifreeze, and windshield cleaning fluid.

Tata Motors, with the support of the Climate and Clean Air Coalition (CCAC) is conducting one of the first ever demonstration projects for secondary loop system in an automobile. Secondary loop systems are specifically designed to safely use mildly flammable refrigerants by maintaining the refrigerant in a separate cooling loop away from the passenger cabin. Two SL systems have been tested in simulated conditions and wind tunnel tests, one using HFO-1234yf and the other using HFC-152a. The results of the test showed that HFC-152a system has a slightly lower cooling capacity than a comparable HFC-134a system but also lower power consumption. The HFO-1234yf system produced a lower cooling capacity and higher power consumption than both other systems, but that doesn't necessarily mean that its performance would not improve in a different system. SL systems also reduced the refrigerant charge compared to the HFC-134a, 39% for HFO-1234yf systems and 50.6% for HFC-152 systems.

Between March and May 2018 Tata will conduct 15,000 km of road trials for both the HFC-152a and HFO-1234yf systems in India. The results of the road trials will be reported in mid-2018. In the future, more road trials in the different area with hot or humid or dry areas will be taken.

Q&A

What about hydrocarbon refrigerants for mobile air conditioning?

Hydrocarbon refrigerants generally have high COP and lower cooling capacity and require larger heat exchangers that are difficult to apply to a vehicle. This presents a significant limitation for their efficient use in MAC systems.

How much fuel can be saved by using a secondary loop system?

The secondary loop can save about 6% of fuel over a standard HFC-134a system, but overall we expect to see a 3% savings due to the additional equipment needed for the secondary loop.

In the EU, many vehicles are switching to electrical power so that the heat pump is required. How would secondary-loop systems work in this situation?

Secondary loop systems can be designed to cool the batteries and there would be no difficulty operating in a hot region where there is no heat pump necessary. Since TATA is only serving the domestic Indian market, there is no need for a heating mode.

Session 5: Opportunities, Challenges, and Experiences with Transitioning to Low-GWP Alternatives

Transition to lower-GWP Alternatives in Article 5 countries – in Air Conditioning Servicing Sector

Ayman Eltalouny, UN Environment (UNEP)

Article 5 (A5) countries are already deeply engaged in the phase-out of HCFCs, which creates both challenges and opportunities for a phase-down of high-GWP HFCs. The conversion of RAC manufacturing sectors is well underway and will likely continue for another 7 or 8 years, resulting in a period of significant overlap between existing HCFC management plans and HFC phase-down plans which will begin in 2024 for most A5 countries. The world is moving from a 'plug and play' period where a limited number of refrigerants dominated the global market, to a 'business not-as-usual' period where most markets in A5 countries will have units operating with HCFCs, HFCs, hydrocarbons (HC) and HFOs. Some of the key challenges moving forward will be managing markets with multiple refrigerants with different technical and safety considerations and the economics of products and services for the variety of refrigerant equipment.

The Montreal Protocol cannot simply focus on the technical aspects of the overlapping commitments. These challenges also bring opportunities for identifying and deploying smart approaches for: training and certification, updating standards, improving reclamation schemes, and providing technical assistance. For training and certification, the Multilateral Fund (MLF) could consider supporting the development of a common code of practice and certification programs, training courses on good practices updated with local technical curricula and supporting regulatory frameworks for certification including elements for enforcement and monitoring. The MLF could support updating of standards and codes for refrigeration and air conditioning as well as building codes and support the interlinkage with MEPS and EE programs. The MLF could support the establishment of reclamation centers, bans on the use of non-refillable cylinders, and common testing facilities. For improved technical assistance, the MLF could support further demonstration projects, establish a global clearing house of good practices with tools and products assessable to all stakeholders, and provide support to and empower local associations.

Transition to low-GWP technologies in Article 5 countries

Ole Nielsen, United Nations Industrial Development Organization (UNIDO)

Global industries are moving away from the use of R-22 to R-410A, but many Article 5 countries are still using R-22. The industry is working to continue optimizing R-410A systems to improve efficiency, but there is a common goal for all regions to find suitable low-GWP refrigerants to replace R-410A. UNIDO has many projects all over the world to support a transition to new refrigerants, but it always needs technology transfer in Article 5 countries. For AC manufacturing, UNIDO is able to support one-to-one conversions of equipment affected by the change in refrigerant and set up necessary safety standards. UNIDO has

completed a number of conversion projects in Argentina, China and Jordan and has on-going projects in Algeria, China, Saudi Arabia, Syria, and Tunisia. There are projects in China, Brazil, and Pakistan which will begin in 1-2 years and additional projects in China, Egypt, and Nigeria expected to start by 2020.

UNIDO's experience thus far with AC manufacturing conversions shows that converting to the use of flammable refrigerants is relatively unproblematic. Third party verification of full installation of new equipment is necessary and post production issues such as addressing applicable safety standards, maintenance and de-commissioning of equipment will require further attention.

The Experience with Implementing the F-Gas Regulation in the European Union

Cornelius Rhein, EU Commission

The EU F-gas Regulation is designed to primarily address emissions of HFCs, but also covers SF₆ and PFCs. It prevents emissions by:

1. preventing leakage through leak checks, control of by-producing, training and qualification programs, and end of life treatment of products and equipment;
2. avoiding use through banning new HFC appliances and certain existing uses; and
3. phasing down HFC supply to ~20% (compared to 2015 consumption levels) in 3-year steps by 2030.

Companies that import bulk HFCs receive a quota every year and are only allowed to place quantities of HFCs on the EU market up to their quota limit. For small and medium enterprises that import HFC equipment can work with an 'authorisation manager' to pool their purchases with other small and medium enterprises (SMEs), and the regulation also allows the import of small amounts (500 t CO₂ equivalent) of HFCs per company and year. Currently, the EU is in full compliance with the F-gas Regulation. For F-gases already on the market, the existing controls are producing a clear price increase between high and very-high GWP refrigerants, which is driving the market to transition quickly to low-GWP alternatives. As the phase-down continues, additional monitoring and reporting will be necessary, because the prices will create an incentive for illegal trade.

Development of HFC Regulations and Lessons Learned – The Canadian Experience

Martin Sirois, Environment and Climate Change Canada

Following broad stakeholder consultations in 2015 and 2016, on 18 October 2017, Canada published final regulations amending the Ozone-depleting Substances and Halocarbon Alternatives Regulations. The new regulations are designed to implement Canada's obligation under the Kigali Amendment to the Montreal Protocol, and climate commitment under the Paris Agreement. The regulations come into effect 150 days following their publication.

The Regulation combines a phase-down of HFC consumption as per the Kigali Amendment schedule with product-specific controls which prohibit the import or manufacture of certain products or systems that contain or are designed to contain HFCs. The phase-down applies to companies importing or exporting bulk HFCs and is supported by a permitting and reporting

system and a quota system. The product-specific controls target: refrigeration and AC systems; mobile air-conditioning systems; foam products; and aerosol products.

The combination of product controls and a phase-down brings many advantages. The phase-down reduces the total amount of HFCs entering the market to meet Kigali commitments, while the product-specific controls ensure the rapid change in the market to new systems using lower-GWP refrigerants. This system also speeds the alignment with US EPA SNAP rules, which is important for common market alignment.

Some lessons learned from development of the regulation include: robust consumption and production data, through surveys or licensing and reporting, which is key for establishing a baseline and providing an early market signal of efforts to meet phase-down requirements; quota systems should be designed to provide flexibility, with baseline years in the past, and provisions to allow late entrants to the market; and quota systems should also not limit specific sectors. For product-specific controls, regulations should be flexible and not pick winners or losers by prescribing specific alternatives. The controls should also allow time for flammability and standards issues to be addressed and preferably start by targeting sectors or applications where alternatives are readily available. Controls should also align with neighbour countries to the extent possible to avoid market disruptions.

Challenges in Using Low-GWP Refrigerants

Gildaro Yañez, Mexico

Mexico faces a number of challenges in implementing the HFC phase-down. R-22 is still the primary A/C refrigerant in use and a large number of refrigeration and air conditioning systems that are not suitable for retrofits, necessitating replacement. Although there are new low-GWP alternatives on the market, many industries are reluctant to change due to a lack of proper equipment and financial support. Professional competence in the refrigeration, air conditioning and heat pump (RACHP) sector is low in Mexico because no professional certification is required and few craftsman, technicians and engineers are trained to use low-GWP refrigerants to meet with the current HCFC phase-out.

Addressing these obstacles in Mexico requires three steps:

- 1) Mexico needs to establish compulsory standards that are aligned with international standards;
- 2) It is important to continue communicating the importance of the refrigerant transition to slow down global warming speed;
- 3) The RACHP industry needs to be upskilled to use low-GWP and natural refrigerant equipment.

Transitioning to Alternatives and Challenges in Japan

Tetsuji Okada, Japan Refrigeration and Air conditioning Industry Association (JRAIA)

The Japan Refrigeration and Air conditioning Industry Association (JRAIA) supports environmental conservation in the RAC sector through a number of activities related to energy efficiency, direct emissions controls and accelerating the transition to low-GWP refrigerants. When selecting appropriate new refrigerants, Japan weighs alternatives based

on four criteria: environmental performance of the refrigerant, safety, energy efficiency, and economic feasibility. Safety in terms of low toxicity and flammability risk are necessary preconditions for all refrigerants. For environmental performance, the alternative must have an Ozone Depleting Potential (ODP) of 0 and a low GWP. The alternative must also have a superior Life Cycle Climate Performance (LCCP) and similar performance at high load cooling to the replaced refrigerant, the alternative must also be available at a reasonable cost that is acceptable in developing countries.

Japan began the process of phasing down the use of HFCs in April 2015 following the revision of the Act on Rational Use and Proper Management of Fluorocarbons (F-gas Reg) to address HFCs and the revision of the High-Pressure Gas Safety Act in 2016, which regulates high pressure gases but also covers toxic and flammable gases. The F-Gas Reg covers the entire lifecycle of the RAC sector by establishing GWP targets for refrigerants used in designated sectors, promoting low-GWP products, registering licensed operators for refilling and operating equipment, and promoting proper destruction and recycling at end of life.

Challenges for Refrigerants at High Ambient Temperatures

Bassam Elassaad, Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC)

There are four main methods for identifying a High Ambient Temperature (HAT) country. The most common, is the average monthly method which looks at the incidence of hours or days at or above a certain temperature. The Parties to the Montreal Protocol adopted the average monthly method and define HAT countries as those that experience temperatures above 35° C for at least two months per year over 10 consecutive years.

HAT conditions are an important consideration for AC and refrigeration because at higher temperatures refrigerants will be operating closer to their critical pressure and the limits of the prescribed high pressure for safe operation. As ambient temperatures increase, condensing temperatures increase, which impacts safety and reduces efficiency. In HAT environments the cooling load of a conditioned space can be up to three times that for moderate climates, necessitating a larger refrigerant charge size. Meanwhile, the reliability of the mechanical systems also degrades due to the higher temperatures.

There are currently four research efforts underway or completed that look at suitable refrigerant alternatives for R-410A in HAT environments:

- Promoting low GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries (PRAHA)
- Egyptian Project for Refrigerant Alternatives (EGYPRA)
- The Oak Ridge National Laboratory (ORNL) High-Ambient-Temperature Evaluation Program for low-global warming potential (Low-GWP) Refrigerants Phase I and II
- The Alternative Refrigerant Evaluation Program (AREP) Phase I and II

It's difficult to compare the results of the studies due to differences in the systems used, system modifications and variations in test procedures, however some tested refrigerants did show promising results in meeting specific current room AC equipment requirements for operation under HAT conditions. For example, the PRAHA study found several available

alternatives with capacities and COP within 10% of R-22. The tests also showed that there is a potential for improvements through further 'soft optimization' of existing systems, but full system optimization is likely needed to exploit the full performance potential of alternative refrigerants. The results also indicate that future optimization efforts should be dedicated to addressing COP losses and increases in compressor discharge temperatures.