ASHRAE-NIST Refrigerants Conference

Gaithersburg, Maryland

October 29-30, 2012

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Monday, October 29

Monday, October 29, 9:15 AM-10:35 AM

Session 1

Chair: Piotr Domanski, Ph.D., Fellow ASHRAE, National Institute of Standards and Technology, Gaithersburg, MD

Refrigerant Transitions … Again

***James M. Calm, P.E.**, Engineering Consultant, Great Falls, VA*

This paper reviews the progression of refrigerants from inception of mechanical refrigeration to the present. It divides historical and current refrigerants into separate generations and discusses the selection criteria distinguishing them. The four generations include slightly overlapping periods based on whatever worked (1830s-1930s), improved safety and durability (1931-1990s), stratospheric ozone protection (1990s-2010s), and attention to global warming (2012-?). The paper discusses the primary refrigerants employed in each period and goes on to examine the viability of the imminent fourth generation, responding to limits and anticipated limits to acceptable refrigerant global warming potential (GWP). The paper presents factors challenging or likely to challenge the fourth generation refrigerants. Among the potential driving factors are efficiency, momentum, prices, litigation and liability, unforeseen suitability issues, local impacts, and political naïveté. The paper summarizes impacts from these concerns, individually or in combination, and their potential to necessitate a subsequent fifth generation. Notwithstanding the controversial and uncertain nature of predictions, the paper suggests an approach to selecting future refrigerants in the absence of ideal choices and of new chemical families that might better approach them. Despite what many practitioners now consider the second transition during their careers, retiring still new but now familiar candidates (or a third transition including the earlier advent of fluorochemicals), the paper concludes that industry must choose between forward-looking selections, which go beyond minimum mandates, or face refrigerant transitions … again.

HFCs in the Atmosphere: Concentrations, Emissions, Impacts

***Stephen A. Montzka, Ph.D.**, National Oceanic and Atmospheric Administration, Boulder, CO*

Concentrations of hydrofluorocarbons (HFCs) have increased in the global background atmosphere in recent years. By 2011 global mean HFC concentrations ranged from ≤ 1 parts per trillion for HFC-227ea to 65 ppt for HFC-134a. Although HFCs in the atmosphere do not deplete ozone, they are greenhouse gases (GHGs) that exert a warming influence on Earth's climate. Total direct heating supplied by all HFCs in 2011 was 0.019 W m-2, which is ≤ 1% of the heating supplied by fossil-fuel-derived carbon dioxide (1.8 W m-2) or anthropogenic methane (0.5 W m-2) in the atmosphere. This warming influence, known also as radiative forcing, is currently small for HFCs because their concentrations are more than 6 orders of magnitude smaller than CO2. A comprehensive assessment of climate impacts of different GHGs, however, also accounts for their influence on climate integrated over time following their release to the atmosphere. This is important particularly for GHGs because some remain in the atmosphere for only days, while others have lifetimes longer than a century. The Global Warming Potential (GWP) provides a measure of the time-integrated radiative forcing arising from an emission of a GHG relative to that from an equivalent emission (by mass) of carbon dioxide. Most HFCs emitted to the atmosphere today have 100-year GWPs ranging from 100 to 14000, which are many times larger than CO2 (GWP = 1). Large increases in use and emission of high-GWP HFCs projected in the future imply a similarly large increase in radiative forcing from HFCs. Such an increase would offset much of the climate gains supplied by the Montreal Protocol in phasing out chlorofluorocarbons. The climate impact of future HFC use, however, would be minimized if the mix of HFCs (or other chemicals) adopted as substitutes had substantially lower GWPs than those in use today.

Monday, October 29, 10:15 AM-12:25 PM

Session 2

Chair: M. Kent Anderson, Life Member, IIAR, Bethesda, MD

Benefits of Addressing HFCs under the Montreal Protocol

Drusilla Hufford, *Cindy Newberg, David Godwin, P.E., Member and Elisa Rim, Environmental Protection Agency, Washington, DC*

Although safe for the ozone layer, continued emissions of hydrofluorocarbons (HFCs)—primarily as alternatives to ozone-depleting substances (ODS) but also from ongoing production of Hydrochlorofluorocarbon (HCFC)-22—will have an immediate and significant effect on the Earth's climate system. Without controls, it is predicted that HFC emissions could negate the entire climate benefits achieved under the Montreal Protocol. HFCs are rapidly increasing in the atmosphere. HFC use is forecast to grow, mostly due to rising demand for refrigeration and air conditioning, particularly in developing countries (Article 5 countries, in the parlance of the Montreal Protocol). There is a clear connection to the Montreal Protocol's chlorofluorocarbon (CFC) and HCFC phaseout and the increased use of HFCs. However, there remains an important opportunity – one the world community may yet seize – to preserve and even build upon the significant climate benefits achieved by the Montreal Protocol by using climate-friendly alternatives and addressing HFC consumption. Recognizing the environmental downsides of continued HFC consumption and emissions, the need for continued HFC use in the near future for certain applications, and the longer term requirement for better alternatives across the board, Canada, Mexico and the United States have proposed an amendment to phase down HFC consumption and to reduce byproduct emissions of HFC-23, the HFC with the highest GWP, arising from production of HCFC-22. The proposed Amendment would build on the success of the Montreal Protocol, rely on the strength of its institutions, and realize climate benefits in both the near and long-term.

Possibilities, Limits, and Tradeoffs for Refrigerants in the Vapor Compression Cycle

Mark McLinden, Ph.D., Member[1], *Piotr Domanski, Ph.D., Fellow ASHRAE*[2], *Andrei Kazakov, Ph.D.*[1], *Jaehyeok Heo, Ph.D.*[2] *and J. Steven Brown, Ph.D., Member*[3], *(1)NIST, Boulder, CO, (2)NIST, Gaithersburg, MD, (3)The Catholic University of America, Washington, DC*

We explore the possibilities for refrigerants having low global warming potential (GWP) by use of two distinct, but complementary, approaches. In the first approach, we evaluate the effect of a refrigerant's fundamental thermodynamic parameters on its performance in the simple vapor compression cycle and several variations on the basic cycle; this defines the limits of what is thermodynamically possible for a refrigerant. The analysis employs evolutionary algorithms, and it identifies the critical temperature, critical pressure, and ideal-gas heat capacity as the most significant fluid parameters. There is a fundamental tradeoff between high efficiency and high volumetric capacity for the vapor compression cycle. Performance differences between refrigerants in the simple cycle can be reduced by proper cycle modifications. In the second approach, we examine more than 56 000 chemical compounds from a public-domain database of chemical structures. A subset of about 1200 candidate fluids is identified by applying screening criteria to estimates for GWP, flammability, stability, toxicity, and critical temperature. The fluids with critical temperatures below 400 K (i.e., those that could be used in current equipment with minor modifications), are dominated by halogenated olefins. Additional chemical families, including ethers and cyclic compounds, are represented among the fluids having critical temperatures above 400 K.

Advances in Microscale Heat and Mass Transfer to Enable a New Generation of Thermally Activated Sorption Heat Pumps

Srinivas Garimella, Ph.D., Member, *Georgia Institute of Technology, Atlanta, GA*

An overview of alternatives to vapor-compression heat pumps, driven by the near-to-long term phase-out of conventional refrigerants, is provided in this paper, followed by a discussion of advances in microscale heat and mass transfer that are leading to the development of a new generation of modular, versatile, small-capacity sorption heat pumps. It is pointed out that absorption, which has been a mature technology for over a century at the large capacities, can also be applied at the smaller scales, in residential and commercial installations in small envelopes through the use of these innovations in microscale heat and mass exchange. Ammonia-water is the working fluid of choice for such compact installations due to its favorable thermodynamic and transport properties, especially the low freezing point and low specific volume of ammonia compared to water vapor. Both falling-film and internal forced-convective flow configurations are presented as viable options for compact absorption systems. Compactness and integration of multiple functions into single components also yields considerable reduction in fluid inventory requirements, connecting plumbing, shipping and installation of these units. Applications include air-conditioning, space heating, and water heating, driven by natural gas, waste heat from collocated processes, and solar thermal energy. Standalone units as well as modular thermal hubs distributed around buildings are facilitated by the availability of these compact heat pumps. The progress in component design, fabrication, controls, and system integration required to take these preliminary demonstration units to full-fledged commercial systems and present viable options to the dominant vapor-compression systems is also discussed.

Monday, October 29, 1:25 PM-2:40 PM

Session 3

Chair: Cynthia Gage, Ph.D., Fellow ASHRAE, EPA, Research Triangle Park, NC

Outlook for Natural Refrigerants

***Clark Bullard, Ph.D., Fellow ASHRAE**, University of Illinois at Urbana-Champaign, Urbana, IL*

The transition to low-GWP vapor compression systems presents technical challenges far more complex than the transition to zero ODP. Simply changing the refrigerant-lubricant mixture is not adequate; this transition requires redesign and optimization of all components because all affect the total equivalent warming impact. Compounding the challenges of maximizing COP are the difficulties of dealing with the toxicity, flammability or high-pressure characteristics of the candidate refrigerants – both natural and synthetic. The task of engineering around these characteristics complicated by inconsistencies and instability in the regulations aimed at minimizing those risks. This paper builds on what is known about the performance of recently-developed prototype systems operating with natural refrigerants (CO2, hydrocarbons, NH3) and their low-GWP competitors, specifically R32 and fluorinated propene isomers of R1234. It also draws upon recent experience using demand-pull regulatory policies to move technologies along the learning curve in order to realize the economies of mass production. Finally it explores the various regulatory and economic forces that will be influencing the competition during the coming decades among low-GWP systems using natural or synthetic refrigerants, and assesses the outlook for natural refrigerants in each of the major market sectors.

Application of CO2 in Supermarkets in Europe

***Tobias Sienel**[1], Bernd Heinbokel[2] and Hans Huff[3], (1)Carrier Commercial Refrigeration, Syracuse, NY, (2)Carrier Commercial Refrigeration, Cologne, Germany, (3)Carrier Commercial Refrigeration, Mainz, Germany*

CO2 as a refrigerant for commercial refrigeration systems in Europe has been gaining increasing customer acceptance and market penetration since being introduced on the market almost a decade ago. The high efficiency of CO2 in commercial refrigeration systems at lower ambient conditions coupled with the relatively low number of hours these systems operate at high ambient conditions in mid to northern Europe have made these systems attractive from an energy efficiency perspective. The very low Global Warming Potential (GWP) of CO2 when compared with typical refrigerants used in these systems coupled with the relatively high leakage rates for typical commercial refrigeration systems have made CO2 very attractive from an environmental perspective. Data is showing that the performance of these systems is increasing year over year as more attention is paid to system design, commissioning, and maintenance. In order for these systems to become competitive globally, the energy efficiency of these systems must become competitive with incumbent refrigerants in higher ambient conditions. There are a number of technology options at various stages of maturity which show a path to achieving this goal.

Opportunities for Ammonia

***Andy Pearson, Ph.D., Member**, Star Refrigeration, Ltd., Glasgow, United Kingdom*

The chemical NH3, known as ammonia, has many unusual properties which make it particularly suitable for use as a refrigerant. This paper examines these properties in the light of over 150 years of continuous use of ammonia in refrigerating systems and explains their implications for system design and operation. The constraints on ammonia use are discussed and a more rational basis for safety rules is proposed. The paper concludes with a review of other possible applications for ammonia as a refrigerant.

Monday, October 29, 3:00 PM-4:40 PM

Session 4

Chair: Bill Dietrich, Member, Daikin McQuay, Staunton, VA

Hydrocarbon Refrigerants for Commercial Refrigeration and Room Air Conditioners

***Daniel Colbourne, Ph.D.**[1] and Rene van Gerwen[2], (1)Refrigerants, Naturally!, Glashütten, Germany, (2)Unilever Engineering Services, Vlaardingen, Netherlands*

This article provides an overview on the use of hydrocarbon refrigerants in commercial refrigeration and air conditioner appliances. The general motivation for the shift towards so-called “natural” refrigerants and in particular, hydrocarbons, is discussed. Different refrigerant options for use in such appliances are summarised and compared against the leading hydrocarbon options: R290 (propane), R1270 (propene) and R600a (iso-butane). A review of various studies associated with the performance of these refrigerants in commercial refrigeration and air conditioning systems is provided alongside theoretical calculations. Given the concern over the flammability of hydrocarbons, safety matters are addressed in detail, covering flammability characteristics, safety standards, charge size reduction and other features which assist with improving safety and flammability risk analysis. More commercial aspects related to costs associated with implementing hydrocarbons and the current status of their use is also mentioned.

2L Flammability Investigation and Risk Assessment Enables Automotive Industry Approval of HFO-1234yf

***Barbara Minor, Member** and Mary E. Koban, DuPont, Wilmington, DE*

HFC-134a is being phased out in the European Union in automotive air conditioning systems due to high global warming potential and perceived excessive leakage from systems. HFO-1234yf has been identified as a potential replacement with excellent environmental properties and cooling performance very similar to HFC-134a. The most significant challenge in the transition to this new refrigerant is that it is mildly flammable. Therefore, it was important to understand the impact and associated risk of using a flammable refrigerant in automotive air conditioning systems. First, basic flammability properties of

HFO-1234yf were determined. Then leakage and ignition testing were conducted under a range of leak scenarios both in vehicles and during service. Finally, the results generated were incorporated into risk assessments to understand potential risks during automotive vehicle air-conditioning use. For HFO-1234yf, this work was conducted and completed through unprecedented industry cooperation and sharing of information. This paper will highlight the extensive flammability testing and evaluations completed which led to the conclusion that HFO-1234yf is safe for use in automotive air conditioning

Risk Assessment of Residential Heat Pump Systems Using 2L Flammable Refrigerants

Thomas A. Lewandowski, Ph.D.[1] *and Kim Reynolds Reid*[2]*, (1)Gradient, Seattle, WA, (2)Gradient, Cambridge, MA*

R-410A is currently the primary refrigerant used in residential AC systems and heat pumps. It is a greenhouse gas, and possible replacements include ASHRAE Class 2L refrigerants, which have reduced global warming potential but are mildly flammable. Accidental releases due to equipment faults or fatigue could potentially result in refrigerant ignition if a sufficient ignition source is present. A risk assessment of R-32, R-1234yf, and R-1234ze(E) in residential split heat pump systems was conducted. The work included CFD modeling, experimental measurements, and a fault tree analysis (FTA) to quantify ignition risks. The assessment indicated that large releases of R-32, R-1234yf and R-1234ze(E) (i.e., 170 g/s for R-32, 78 g/s for R-1234yf and R-1234ze(E)) from units installed in basements, garages or attics would not reach flammable concentrations in areas where a sufficient ignition source might be present. Large releases of all three refrigerants from a unit located in a utility closet can generate flammable concentrations in the utility closet, although the time the refrigerant concentration was flammable was brief (70 s for R-32 and R-1234yf and 45 s for R-1234ze(E)). Flammable concentrations did not occur with smaller leaks of R-1234ze(E) and R-1234yf (e.g., 1.5 g/s or less) in utility closets. The FTA estimated that the risks of refrigerant ignition due to an accidental leak of R-32, R-1234yf and R-1234ze(E) were 9×10^{-5}, 2×10^{-5} and 2×10^{-5} ignition events per unit per year, respectively. For comparison, the risk of a significant home fire in the US is 1×10^{-3} per home per year. The FTA in this study considered refrigerant ignition and did not determine whether a fire would ensue due to the ignition of surrounding materials. The analysis also did not include potential mitigation factors that would further reduce the probability of refrigerant ignition.

Monday, October 29, 4:15 PM-4:40 PM

Panel Discussion

Chair: Piotr Domanski, Ph.D., Fellow ASHRAE, National Institute of Standards and Technology, Gaithersburg, MD

Why is there a difference in the dominant focus regarding refrigerants within Europe, North America and Asia?

Since the first major switch-over to replacement/alternate refrigerants in the mid 1990's, it has become clear that different regions of the world pursue this topic differently. For example, while almost every domestic refrigerator/freezer in Western Europe uses a hydrocarbon refrigerant, North America is using exclusively R134a in this application. In this panel discussion, three leading experts representing academia and governmental policy makers from Asia, Europe and North America will offer their views on the cultural and technical driving factors for the use of refrigerants in different areas of the world. In addition, they will respond to questions from the audience.

1. *Guangming Chen, Zhejiang University, Hangzhou, China*
2. *Dennis Clodic, EReIE, Paris, France*
3. *Drusilla Hufford, EPA, Washington, DC*

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Tuesday, October 30

Tuesday, October 30, 9:00 AM-10:40 AM

Session 5

Chair: Donald Bivens, Steering Committee, NIST RC, Kennett Square, PA

Introduction to Alternatives for High-GWP HFC Refrigerants

J. Steven Brown, Ph.D., P.E., Member*, The Catholic University of America, Washington, DC*

This paper is an introduction to alternatives to high-GWP HFC refrigerants, particularly halogenated olefins, and more specifically fluorinated propene isomers. A summary of fluorinated propene isomer-based blends (AC-1, DP-1, Fluid H, and JDH) that were investigated as part of the Society of Automotive Engineer's (SAE) Cooperative Research Program (CRP150) is provided. These blends were designed to possess GWP values less than 150 in order to meet the European Union's Mobile Directive; however, they were later abandoned because some of the blend components demonstrated concerns related to toxicity, ODP, and/or reactivity. After the abandonment of these blends, CRP1234 was initiated by SAE to focus its development efforts on R-1234yf. In addition to R-1234yf, a few other olefins are being investigated as potential refrigerants by the HVAC&R industry, as indicated by the level of patent activity. To demonstrate the performance potentials of some of these blends, simulations are conducted for several fluorinated propene isomer-based blends for typical unitary A/C applications. In addition to these simulations, some of the advantages and disadvantages of fluorinated propene isomers are discussed.

Environmental Properties of HFOs

Stephan Henne[1]*, D.E. Shallcross*[2]*, S. Reimann*[3]*,* ***P. Xiao***[2]*, S. Boulos*[3]*, A.C. Gerecke*[3] *and D. Brunner*[3]*, (1)Swiss Federal Laboratories for Material Science and Technology, Dubendorf, Switzerland, (2)University of Bristol, Bristol, United Kingdom, (3)Empa, Dubendorf, Switzerland*

Currently several unsaturated hydrofluorocarbons, also termed hydorfluoroolefins, (HFO) are evaluated as replacements for previously used saturated hydrofluorocarbons (HFC) with large global warming potentials. Some of these new HFOs are oxidized in the troposphere and form the persistent and mildly phytotoxic trifluoroacetic acid (TFA) with larger molecular yields than those of currently used HFCs. The most important new compound in terms of expected future emissions and TFA yield is HFO-1234yf (2,3,3,3-tretrafluoropropene), which may replace HFC-134a (1,1,1,2-tetrafluoroethane) in mobile air conditioners. Here we review previous findings on TFA in the environment and compare recent TFA measurements in Switzerland with those from the 1990s when HFCs with considerable TFA yields were introduced. Changes in rainwater concentrations were not significant for two sites in northern but were positive for one site in southern Switzerland, where photochemistry is accelerated. The latter may point towards enhanced production of TFA from increased HFC background concentrations during the last decades but cannot be generalized due to the large variability and sparsity of the observations. By means of atmospheric chemistry and transport modeling we investigated TFA concentrations in rainwater and TFA deposition rates that would result from a complete switch of the European vehicle fleet to HFO-1234yf. We estimated total European HFO-1234yf emissions of 11.0 to 19.2 Gg yr-1 for 2020. Since the lifetime of HFO-1234yf is relatively short, maximal TFA concentrations and deposition rates were simulated close to emission centers. Predicted maximal summer-time TFA concentrations in European rainwater reached up to 7,700 ng L-1, which is more than one order of magnitude smaller than the no-effect level of the most sensitive fresh-water algae. Maximal annual TFA concentrations were predicted to stay below 2,500 ng L-1. If HFO-1234yf emissions remain within the envisaged range our results indicate no direct effect of additional TFA on the environment. Nevertheless, uncertainties remain in our understanding of natural TFA sources and cycling and should be addressed in future research. This issue could gain importance, if HFO-1234yf will be used also for other applications or HFOs with similar TFA yields would be introduced.

Thermal and Chemical Stability of HFOs

Ngoc Dung (Rosine) Rohatgi, Ph.D., Member*, Spauschus Associates Inc., Sylva, NC*

With the growing concern over global warming and the signing and ratification by many countries of the Kyoto Protocol, new refrigerants with low global warming potential (GWP) such as hydrofluoroolefins HFO-1234yf and HFO-1234ze with GWP under 10 have been proposed as replacements for hydrochlorofluorocarbons (HCFC) and hydrofluorocarbons (HFC). The long-term reliability of air-conditioning and refrigeration systems of the past fifty years depends on the thermal stability of the refrigerant/lubricant working fluids and their compatibility with the materials of construction of the compressor. This paper focuses on the thermal and chemical stability of the refrigerant/lubricant working fluids. Refrigerants HFO-1234yf, HFO-1234ze and a mixture of HFO-1234yf and R-32 (50/50 by weight) were tested with two POE oils (a mixed acid and a branched acid POE), and one PVE oil. Using the fluoride ion concentrations after aging as indicators of refrigerant decomposition and Total Acid Numbers (TAN) as indicators of lubricant decomposition, the stabilities of the different refrigerant/lubricant mixtures (when aged at 175^{o}C for 14 days in sealed tubes) were compared.

Thermophysical Properties, Heat Transfer, and Pressure Drop of HFOs

Alberto Cavallini, Ph.D., Fellow ASHRAE[1]*, J. Steven Brown, Ph.D., P.E., Member*[2] *and* **Claudio Zilio, Ph.D.**[1]*, (1)University of Padova, Padova, Italy, (2)The Catholic University of America, Washington, DC*

This paper considers the heat transfer and pressure drop performance potentials of halogentated propene isomers during in-tube condensation and in-tube flow boiling using the penalty factor and total temperature penalization concepts, respectively. In particular, five isomers are considered: R-1233xf, R-1233zd(E), R-1234yf, R-1234ze(E), and R-1243zf. In addition, to these five pure fluids, the heat transfer and pressure drop performance potentials of five R-32/R-1234yf blends are considered. The paper also presents thermophysical property estimations for the five pure fluids relative to R-134a, R-245fa, and R-123. The thermophysical properties considered are the ones that influence the heat transfer and pressure drop performance potentials, and include the thermodynamic properties temperature, pressure, density, latent heat of vaporization, and specific heat, and the transport properties thermal conductivity and viscosity. The paper also presents a literature review of relevant articles for condensation and boiling heat transfer and pressure drop of fluorinated propene isomers.

Tuesday, October 30, 11:00 AM-12:15 PM

Session 6

Chair: Karim Amrane, Ph.D., Member, AHRI, Arlington, VA

Alternatives to High GWP HFC Refrigerants: Residential and Small Commercial Unitary

Chun-Cheng Piao, Ph.D., Member*, Shigeharu Taira, Ph.D., Michio Moriwaki, Keisuke Tanimoto, Katsuki Mochizuki and Akinori Nakai, Daikin Industries, Ltd., Osaka, Japan*

The Montreal Protocol is succeeding and now the global environmental challenge is shifting from ozone depletion to global warming. To address this challenge, several new refrigerants have been proposed, and some traditional refrigerants are being re-evaluated, in order to find a balanced solution which satisfies both global environmental demands, and also consumer needs. This study focuses on residential and small commercial unitary systems evaluating proposed new refrigerant candidates. These refrigerants were tested extensively in drop-in tests. The authors come to the conclusion that one of the tested refrigerants has the potential to provide the best, most balanced solution for residential and small commercial unitary applications.

Alternatives to High GWP HFC Refrigerants: Air-Conditioning, Heating and Refrigeration Applications

Rajan Rajendran, Ph.D., Associate Member and ***Hung Pham,*** *Emerson Climate Technologies, Inc., Sidney, OH*

This paper will review the status worldwide on technical and policy search for next-generation refrigerants with both low Global Warming Potential (LGWP) and low Life Cycle Climate Performance (LCCP) with focus on stationary refrigeration applications. Synthetic HFO blends and natural refrigerants offer potential solutions in all applications, but all involve trade-offs among Global Warming Potential (GWP), efficiency, safety, and cost. With increasing concerns about energy prices and the desire for higher efficiencies, there is even more pressure in finding a Low-GWP refrigerant solution that is affordable and can sustain efficiency and reduce charge requirement. Theoretical analyses and test results from drop-in compressor and system tests will be presented along with LCCP analysis for typical US stationary refrigeration applications and recommendations made for the path forward.

Alternatives to High GWP HFC Refrigerants: Chiller Applications

Kenneth E. Hickman, Ph.D., Life Member*, Johnson Controls, York, PA*

This report presents the characteristics of lower-GWP chiller refrigerant alternatives offered by refrigerant manufacturers for consideration and testing in the "Low-GWP Alternative Refrigerants Evaluation Program" administered by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI). Alternatives have been identified for the chiller refrigerants R-134a, R-410A, and R-22. An alternative for R-123 also has been proposed. Test results for some of the refrigerants are presented. There are no "ideal" refrigerants in the list of alternatives to R-134a, R-410A, and R-22 if "ideal" is defined as having a GWP of 150 or less, an A1 ASHRAE safety rating, and near-zero temperature glide. Refrigerants with GWPs of 700 or more, an A2L safety rating, and – in some cases an appreciable temperature glide - need to be considered for the future.

Tuesday, October 30, 1:15 PM-2:30 PM

Session 7

Chair: M. Kent Anderson, Life Member, IIAR, Bethesda, MD

AHRI Low-GWP Alternative Refrigerant Evaluation Program

Phillip Johnson, P.E., Member[1]*, Karim Amrane, Ph.D., Member*[2] *and Xudong Wang, Ph.D., Member*[2]*, (1)Daikin McQuay, Staunton, VA, (2)AHRI, Arlington, VA*

In response to environmental concerns raised by the use of high global warming potential (GWP) refrigerants, the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) launched an industry-wide cooperative research program, AHRI Low-GWP Alternative Refrigerants Evaluation Program (Low-GWP AREP), to identify and evaluate promising alternative refrigerants for major product categories. These categories include air conditioners, heat pumps, chillers, water heaters, ice makers and refrigeration equipment. This paper provides an overview of the program, including the program's scope and procedure. A series of alternative refrigerant candidates being evaluated in the program will be introduced. The refrigerant candidates' thermodynamic cycle calculated performance and real testing results for various applications are presented up to the current status of the program.

Low Refrigerant Charge with a Focus on Microchannel Heat Exchangers

Pedrag S. Hrnjak*, University of Illinois at Urbana-Champaign, Urbana-Champaign, IL*

This paper presents an overview of the reasons for charge reduction in air conditioning and refrigeration systems and discusses strategies for charge reduction: in compressors (oil), vessels, pipes, and heat exchangers. The focus is on heat exchangers, microchannel in particular. In addition to a trivial reduction of internal volume as a strategy for charge reduction, the effect of mass flux on void fraction and needed manipulation of circuiting is presented. A framework and example of comparison between refrigerants based on their potential for low condenser charge is provided.

Laying the Groundwork for an International Refrigerant Management Plan

***Danny Halel**, Hussmann Corporation, Bridgeton, MO*

Refrigeration/air conditioning applications are growing in the United States as well as worldwide, since they are critical contributors to the health, comfort, and welfare of humanity. However, the use of refrigerants have consequences for the environment if the refrigerants are not properly selected and managed throughout their lifecycle. Refrigerant manufacturers, contractors, and users are frequently falsely accused of mismanagement and abuse of refrigerants. This report intends to lay the groundwork for a future Refrigerant Management Implementation Plan. Proper cradle to grave management is necessary to minimize the environmental impact and to ensure that suitable refrigerants are used by the HVAC&R industry to meet growing demand. In the USA, every household has at least one refrigerator; over 90% have A/C systems. Nearly all passenger vehicles and commercial trucks are equipped with air-conditioning. There are over 35,000 commercial refrigeration systems, and thousands of mobile refrigeration systems on the roads. In addition, reefer ships, and thousands of commercial chillers and heat pumps are used in commercial, industrial and institutional applications. All of these applications utilize refrigerants. Direct refrigerant emissions are estimated by the EPA to represent about 3% of global greenhouse gas emissions. The Indirect Effect is overall a larger portion of Climate Change Emissions than the Direct Effect, and is minimized by the use of the available refrigerant that permits the most efficient equipment design possible. Therefore, for all but high emission applications, the equipment and system efficiency will have a greater bearing on environmental impact than the GWP of the particular refrigerant used. Nevertheless, even if the lowest GWP refrigerants and/or most efficient equipment technologies are used, refrigerant releases to the environment should be minimized in order to minimize the total environmental impact. It is to this objective that the Committee directs its work.

Tuesday, October 30, 2:30 PM-2:55 PM

Panel Discussion

Chair: Piotr Domanski, Ph.D., Fellow ASHRAE, National Institute of Standards and Technology, Gaithersburg, MD

Refrigeration and air conditioning in 2032: Impacts of regulations, technology, and consumer preferences

While industry transition to low-GWP refrigerants is imminent because of the climate change concerns, other significant drivers are in place that will affect direction the industry transformation will take and the speed at which these changes will occur. In this panel discussion, four leading experts representing academia, equipment manufacturers, refrigerant producers, and European industrial heating and cooling engineering companies will offer their views on the future use of refrigerants and respond to questions from the audience

4. *Clark Bullard, Ph.D., University of Illinois at Urbana-Champaign, Urbana, IL*
5. *Andy Pearson, Ph.D., Member, Star Refrigeration, Ltd., Glasgow, United Kingdom*
6. *Steve Kujak, Ingersoll Rand, La Crosse, WI*
7. *Mark Spatz, Honeywell, Buffalo, NY*

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