Refrigerants for commercial refrigeration applications

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EMERSON
Climate Technologies

Contents

Executive summary

The refrigeration industry has supported global efforts to protect the environment by phasing out chlorine-containing refrigerants in accordance with the Montreal Protocol. These actions have significantly cut chlorine in the atmosphere and are starting to repair the ozone layer.

Today, there is more attention on climate change and reducing greenhouse gases. Carbon dioxide is by far the most significant greenhouse gas, produced mainly by burning fossil fuels for electrical generation and transportation. Since refrigeration equipment consumes energy, energy-efficient designs are important to reducing carbon dioxide production.

If refrigerant gas escapes from a system, it can also contribute to direct global warming. System manufacturers and contractors are working hard to contain refrigerant leaks.

For a refrigerant to be considered a long-term option it must meet three criteria — it must be safe; it must be environmentally friendly; and it must provide excellent performance benefits — thus resulting in zero ozone depletion with low Global Warming Potential (GWP).

Several non-halogen substances, including ammonia, carbon dioxide and hydrocarbons, will also work as refrigerants. All these substances can be refrigerants for the right application if the system can be designed to meet key selection criteria. Component and equipment manufacturers continue to research how these refrigerants perform in systems.

Hydrofluorocarbons (HFCs) are non-ozone-depleting, non-flammable, recyclable and energy-efficient refrigerants of low toxicity that are used safely worldwide. Although HFCs are the best environmental and economic choice today, the global sustainability of HFCs requires a focus by the industry on refrigerant containment and energy efficiency.

Research has shown that properly designed and maintained systems using HFC refrigerants provide the lowest GWP and zero ozone depletion. They are also a safe and cost-effective solution that will serve us well into the future.

In this paper, the long-term, non-ozone-depleting replacements for hydrochlorofluorocarbon (HCFC) R-22 are also discussed. The experience to date shows that these alternatives, when used in optimized systems, provide performance superior to the baseline HCFC refrigerant. Other refrigerant choices, such as carbon dioxide and hydrocarbons, are also discussed, along with their relative merits to HFCs.

Emerson Climate Technologies is committed to providing solutions that improve human comfort, safeguard food and protect the environment. We recognize that this is a difficult balance, but remain optimistic. We are confident that we can develop solutions that provide efficient commercial refrigeration without compromising our global environment. The following paper discusses the factors that we feel are most important for meeting this challenge.

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CAUTION

POE must be handled carefully and the proper protective equipment (gloves, eye protection, etc.) must be used when handling POE lubricant. POE must not come into contact with any surface or material that might be harmed by POE, including without limitation, certain polymers (e.g. PVC/CPVC and polycarbonate).

Introduction and background

Scientific data supports the hypothesis that chlorine from refrigerants has depleted the earth's ozone layer and is linked to a rise in skin-related diseases[1]. The air conditioning and refrigeration industry has supported global efforts to protect the environment by introducing non-chlorine-containing refrigerants. The Montreal Protocol, established in 1987 and later revised, provides guidelines for individual country legislation, setting timetables for the phase-out of chlorine-containing refrigerants. Today, 196 nations have become party to the Montreal Protocol.

The effort started with an emphasis on cutting chlorofluorocarbon (CFC) refrigerants. Work in the late 1980s and early 1990s centered on eliminating CFCs which were used in foam blowing, cleaning and refrigeration applications and centrifugal chillers for air conditioning. By the end of 1995, developed countries stopped producing CFCs, and they are no longer used in new equipment today. These actions have significantly reduced atmospheric chlorine and are starting to repair the ozone layer.

In 1997 the Kyoto Protocol, signed and ratified by many nations around the world, focused attention on the impact of human activity on climate change. As a result, there is now more attention on global warming. Although the Kyoto Protocol does not apply to the United States, our industry has worked to lower the impact of refrigerants on climate change with higher-efficiency refrigerants and system designs.

In 1997 the Air-Conditioning and Refrigeration Institute (ARI) finished a major international testing program entitled the Alternative Refrigerants Evaluation Program (AREP). The AREP report indentified several suitable HFC replacements for HCFC R-22. In the USA and Europe, these HFC replacements are already being widely used. Some of these replacement refrigerants have different operating characteristics than HCFC R-22, but they all eliminate chlorine and potential ozone depletion, leaving climate change as the focus for future regulations and control.

Environmental drivers

There are two factors important to the discussion of the environmental impact of refrigerants: ozone depletion and global warming.

Ozone depletion

The ozone layer surrounding the earth is a reactive form of oxygen 25 miles above the surface. It is essential for planetary life, as it filters out dangerous ultraviolet light rays from the sun. Depleted ozone allows more ultraviolet light to reach the surface, negatively affecting the quality of human, plant, animal and marine life.

Scientific data verifies that the earth's ozone layer has been depleted. The data also verify that a major contribution to ozone depletion is chlorine, much of which has come from the CFCs used in refrigerants and cleaning agents.

Research has shown that even the chlorine found in R-22 refrigerants can be harmful to the ozone layer. The need to protect the earth's ozone has resulted in new government regulations and HFC refrigerants. Since HFCs are chlorine free, they will not damage the ozone layer.

The greenhouse effect

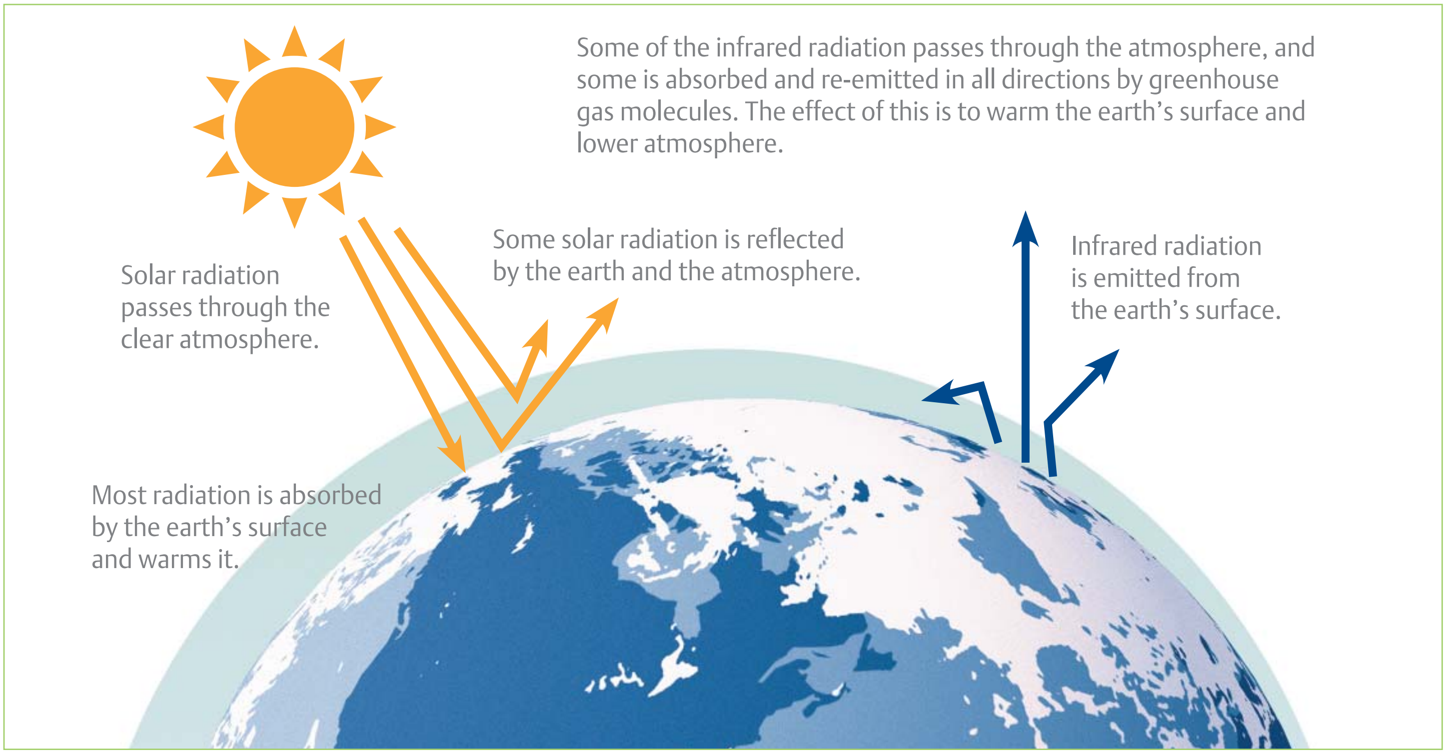


Figure 1

Climate Change

According to the National Academy of Scientists, the temperature of the earth's surface has risen by about one degree Fahrenheit (0.5 degree Kelvin) in the past century[2]. There is evidence that suggests that much of the warming during the last 50 years is because of greenhouse gases, many of which are the by-product of human activities. Greenhouse gases include water vapor, carbon dioxide, methane and nitrous oxide, and some refrigerants. When these gases build up in the atmosphere, they trap heat. The natural greenhouse effect is needed for life on earth, but scientists believe that too much greenhouse effect will lead to climate change. **Figure 1** shows the mechanism of this global warming process.

Carbon dioxide (CO_2) is one of the major greenhouse gases. Vegetation is the primary generator of CO_2, along with natural organic materials decomposing.

Burning fossil fuels also adds CO_2 to the atmosphere. Fossil fuels are used in power plants around the world to produce electricity for vital social needs. According to the U.S. Energy Information Administration, nearly 30 billion metric tons of energy-related carbon dioxide were produced in 2007[3]. In comparison, total annual HFC production globally is less than 0.001 percent of this figure. It is estimated that HFCs will contribute no more than three percent of greenhouse gas emissions by 2050. Energy-efficient refrigeration equipment saves energy and cuts energy-related carbon dioxide emissions.

Total Equivalent Warming Impact (TEWI)

Global Warming Potential (GWP) is a direct measure of global warming that considers only the direct effect of the refrigerant as a greenhouse gas when it escapes into the atmosphere. Essentially, all alternatives to R-12 and R-502 have substantially less direct GWP and are, therefore, considered a move in the right direction. As a result, refrigerants with a Global Warming Potential (GWP) of less than 4,000 have been accepted; however, some European countries are using 2,000 as a maximum GWP (reference GWP for R-11 = 4,000)[4].

The refrigeration industry developed TEWI to measure the impact of various activities on global warming. TEWI is widely accepted as the best measure of global warming, because it accounts for greenhouse gases from direct emissions of operating fluids together with the sizable energy-related CO_2, as seen in **Figure 2**. This global warming calculation includes the effects of system efficiency and the source of the electricity (coal, nuclear, hydroelectric) and the direct effect of the refrigerant when it escapes into the atmosphere. The number varies according to the leakage rate and type of power used. Higher energy efficiency of some refrigerants can lower the indirect effect and offset a somewhat higher GWP.

Direct global warming is an issue only if the refrigerant leaks or is released from the refrigeration system; thus, refrigerant containment in the system is the key to cutting the direct global warming effect. The best way to do this is with low-charge system designs, the quick repair of all leaks and the recovery of refrigerant during service operations.

Indirect global warming is a function of the efficiency of any piece of equipment. In a refrigeration system, the compressor efficiency, system design, and thermodynamic and heat-transfer properties of the refrigerant affect the energy efficiency of the equipment. Indirect global warming takes into account the energy efficiency, and the power source.

Global warming impact

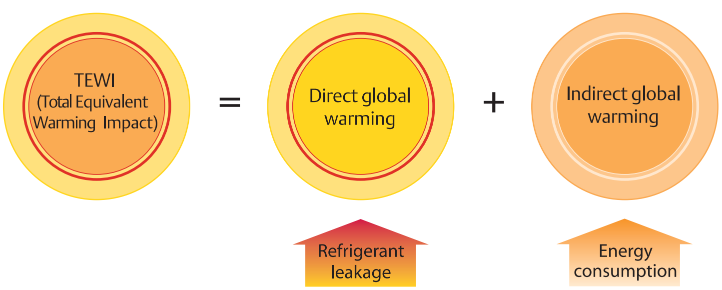


Figure 2

Refrigerant options

Refrigerant	Type	GWP
R-12	CFC	10900
R-502	CFC	4700
R-22	HCFC	1810
R-134a	HFC	1430
R-404A	HFC	3922
R-407A	HFC	2107
R-407C	HFC	1774
R-410A	HFC	2088
R-422A	HFC	3143
R-422D	HFC	2729
R-32	HFC	675
R-1234yf	HFO	4
HC-290	Propane	20
R-717	Ammonia	0
R-744	Carbon Dioxide	1

Figure 3

Electrical generation can come from fossil fuels, hydropower or nuclear power. The implication is that a less efficient system uses more electricity, and thus has a higher TEWI.

It is likely that global warming will be important in driving the trend to more efficient refrigerants, as energy consumption is the main contributor to global warming by most equipment. In dealing with the changing refrigerant environment, Emerson has adhered to a strategy that permits us to serve our markets with products that provide performance, reliability and minimum risk, while moving as rapidly as possible to chlorine-free alternatives.

TEWI and refrigerants

Global warming is a significant consideration in the selection of future refrigerants. Some refrigerants have a higher direct GWP than others; however, direct global warming alone can be misleading in understanding the effect of various refrigerant alternatives. TEWI helps to assess the climate-change impact fairly, as it takes into account the direct (refrigerant emissions) and indirect (system power consumption/efficiency) effects in evaluating global warming. Today's HFC refrigerants appear to be good options when comparing the total global warming impact to that of halogen-free refrigerants.

TEWI highlights the need to control leaks to reduce global warming from the refrigerant. As shown in **Figure 3**, indirect global warming — that which can be best dealt with by using higher-efficiency refrigerants and the design of higher-efficiency systems — can have a far greater impact than direct global warming. Refrigerant that does not get into the atmosphere does not cause global warming.

The Kyoto Protocol was established in 1997 in response to global warming concerns. Developed countries are challenged with cutting greenhouse gases by an average of 5.23 percent from 1990 levels between the years 2008 and 2012. The protocol focuses on six gases, which it views as being considered and controlled as a total package. These gases include CO_2, CH4, N2O, HFCs, PFCs and SF6.

As we consider the refrigerants available to manufacturers and the potential global warming impact of each, we believe it is likely that most commercial refrigeration applications will stay with HFC options, such as R-404A, R-507, R-134a, R-407C and R-410A. The efficiency performance and cost advantages of these refrigerants outweigh the disadvantages associated with higher pressures and direct GWP.

Emerson Climate Technologies supports TEWI and expects that this measurement tool will become the representative criterion in selecting future refrigerants. Using the right refrigerant in energy-efficient refrigeration equipment can lower greenhouse gas emissions.

Regulations & Timing

The Montreal Protocol was revised to call for a production phase-out of HCFC refrigerant applications by 2020; however, concerns about the proximity of the production cap and the impact of Environmental

Protection Agency (EPA) regulations have caused many end-users and OEMs to work on system redesigns to cutout

HCFC phaseout timeline

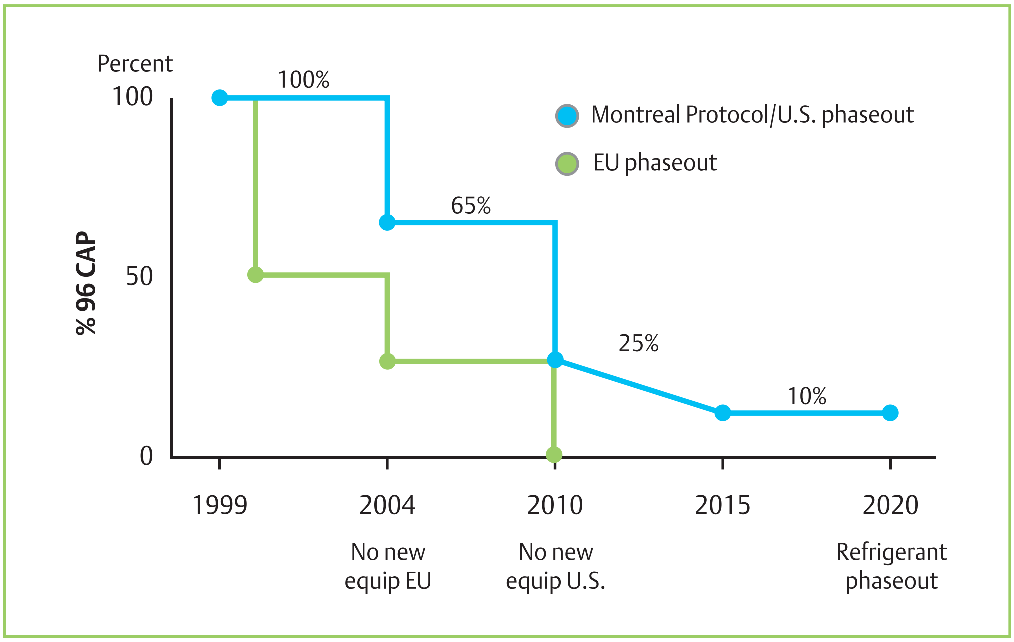


Figure 4

HCFC refrigerants. As shown in **Figure 4**, allowable HCFC production levels drop with time, with the next significant cut planned in 2020.

The Montreal Protocol supports HCFCs to aid in the transition from CFCs; however, HCFC consumption will be limited relative to historic usage of CFC and HCFC on an ozone-depletion weighted basis, during the transition. The EPA has established U.S. regulations, which control future use of HCFCs according to a schedule that the agency and industry believe is right.

The EPA is monitoring continually the U.S. compliance with the Montreal Protocol and has developed a schedule to monitor progress toward the total phase-out of HCFCs. The United States Clean Air Act established regulations for implementing this phase-out. After 2010 chemical manufacturers may still produce R-22 to service existing equipment, but not for use in new equipment. Equipment manufacturers in the United States must not produce new systems using R-22. In 2020 use of existing refrigerant, including recovered and recycled refrigerant will be allowed beyond 2020 to service existing systems, but chemical manufacturers will no longer be able to produce R-22.

In the European Union, the F-Gas Regulation[5] took effect as of July 2007. It requires leak inspections, leak-detection systems, recovery, and training and certification. Manufacturers must comply with the requirements on labeling and leak checks. The effectiveness of the F-Gas Regulations will be reviewed in 2011. See EPEEGlobal.org for further details.

Refrigerant decisions are also impacted by other regulations on product design and application. For example, Underwriters Laboratories, Inc. (UL) modified the pressure standard for refrigerants in air conditioning and refrigeration systems, making it possible to safely apply the higher-pressure refrigerant alternatives[6].

It is important for users to continuously monitor and understand the impact of all the various legislative actions to our industry. In Europe, refrigerant choices are also impacted by commercial incentives, such as refrigerant taxes, depending on GWP and energy-efficiency certification schemes.

Regardless of regulations, many OEMs have already launched environmentally friendly systems in response to competitive pressures. Since 1990, Emerson has developed and released a series of new HFC products to support the industry's need for chlorine-free systems. Products designed to operate with R-404A, R-507, R-134a, R-407C and R-410A are now available.

Criteria for refrigerant selection

The desirable characteristics for a widely used refrigerant include:

- Environmental acceptability
- Chemical stability
- Materials compatibility
- Refrigeration-cycle performance
- Adherence to nonflammable and nontoxic guidelines, per UL
- Boiling point

The components of a refrigerant mixture are chosen based on the final characteristics desired. These characteristics could include vapor pressure, transport properties, lubricant and material compatibility, thermodynamic performance, cost, flammability, toxicity, stability and environmental properties. The proportions are chosen based on the exact characteristics desired in the final product.

ARI established AREP to evaluate refrigerant alternatives. More than 180 AREP reports were approved and released to the public when the committee finished testing in 1997. This testing led to the widespread use of HFC refrigerants to replace R-22.

Safety

As the air conditioning and refrigeration industries move away from the few CFC and HCFC refrigerants still in circulation, the safety of new refrigerants must be considered. Refrigeration safety issues fall into four major areas:

Pressure — almost all the new refrigerants operate at a higher pressure than the refrigerants they replace. In some cases the pressure can be substantially higher, which means that the refrigerant can be used only in equipment designed to use it and not as a retrofit refrigerant.

Material compatibility — the primary safety concern here is with deterioration of materials, such as motor insulation, which can lead to electrical shorts, and seals, which can result in leaks.

Flammability — Leakage of a flammable refrigerant could result in fire or explosions. Many new refrigerants are zeotropes, which can change composition under some leakage scenarios. So it is important to understand the flammability of the refrigerant blend, and what it can change into under all conditions.

Toxicity — during the transition to HFCs, some countries have explored or applied toxic refrigerant options. These alternatives may offer system performance benefits, but they can also be highly dangerous. It is the view of Emerson that toxic refrigerant options should not be used for commercial refrigeration, especially considering that HFCs can deliver the equivalent or better efficiency and performance. The major refrigerant manufacturers, equipment manufacturers and safety-standard setting agencies, such as UL and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), have extensively studied and then rated the safety aspects of proposed new refrigerants according to each of the factors listed above. The intent is to use only refrigerants that are at least as safe as those being replaced.

Chlorine-free refrigerants (HFCs)

The selection and approval of acceptable long-term refrigerants is a complex task. The ever-shifting legislative environment, the phase-out of CFCs and HCFCs, the availability of alternate refrigerants and many other factors are just a few of the issues that must be taken into account.

Based on these factors, Emerson Climate Technologies has cited the following key criteria for evaluating and approving HFC refrigerants for use in Emerson products:

Global warming should be reviewed, based on the TEWI approach; therefore, the combined direct global warming and indirect global warming, which varies with energy efficiency, should be less than the refrigerants being replaced.

Safety must be maintained. New refrigerants should be nontoxic, with a Threshold Limit Value (TLV) minus Time-Weighted Average (TWA)[7] greater than 400 parts per million (ppm), and nonflammable. If they are not, steps must be taken to ensure that the refrigerants are properly used in equipment and facilities designed to provide adequate safety protection. Maximum system pressures must be no greater than current acceptable limits for retrofit applications. Emerson approves only refrigerants that meet UL standards. See Emerson Climate Technologies, Inc. Accepted Refrigerants/Lubricants (Form 93-11).

It is desirable that lubricants work with current oil-control technology, meet current or improved durability requirements and be backwards compatible with mineral-oil systems. Material compatibility between the new refrigerants, lubricants and materials of construction in compressor and system components must be maintained.

It is highly desirable to have one lubricant solution that works with all the alternative refrigerants, including HFC and HCFC retrofit chemicals. One lubricant that works with all the approved chemicals makes the service and long-term refrigerant use easier.

Service procedures for equipment should remain simple. Using refrigerant blends should not require unreasonable service procedures.

The performance of new refrigerants should be similar to the refrigerants they are replacing. Regardless of the specifications of individual manufacturers, a refrigerant must have zero ozone depletion and low GWP to be considered a long-term option.

HFCs

HFCs, or hydrofluorocarbons, are chemicals used in air conditioning and refrigeration applications. They are non-flammable, recyclable, energy-efficient refrigerants of low toxicity that are being used safely worldwide.

Technical and Economic Assessment Panel (TEAP) of the Montreal Protocol on Substances that Deplete the Ozone Layer reported in 1999 that HFCs are needed for the safe and cost-effective phase-out of CFCs and HCFCs and are essential substitutes for these products. Also, HFCs are needed to phase-out HCFCs in developing countries. As replacements for less energy-efficient, older equipment, HFC systems conserve energy and reduce global warming gases at electric power plants. These systems are being used responsibly, including recovery and reuse of HFCs to design of HFC-producing plants, with the goal of zero HFC emissions.

Substituting HFCs for CFCs has lowered the impact of greenhouse gas emissions, as HFCs cut total greenhouse gas release. Current technology has reduced greenhouse gas discharged by more than 80 percent since 1990. Projections show that by 2050, HFC emissions will make up less than two percent of potential future contributions for all greenhouse gases, as identified in the Kyoto Protocol[8].

Depending on the country of use, HFC emissions management is being conducted through mandatory recovery and non-regulatory means, voluntary measures and industry-government partnerships. This involves engaging jointly in research and communication to find new technologies, designs and processes to manage HFC emissions and to enhance product energy efficiency.

The HFCs and equipment being produced for refrigeration appear to be satisfactory for these applications; however, there are several areas in which they differ from the refrigerants they are replacing:

- They require polyol ester (POE) oil rather than mineral oil.
- Most of the HFCs are mixtures, which can behave differently than pure compounds under some conditions.
- HFCs have higher vapor pressures than the refrigerants they are replacing, which can affect the settings of controls, valves and safety devices.

Mixtures

As mentioned earlier in this paper, refrigerant manufacturers have been unsuccessful in developing single-component, high-pressure alternatives to CFCs that have zero-ozone-depletion potential, adequate performance, good reliability and safety. So HFC mixtures (also called blends, azeotropes, near-azeotropes and zeotropes) are widely used.

Mixtures have advantages and disadvantages when compared to pure substances. Mixtures allow the advantage of tailoring the final refrigerant characteristics for superior efficiency, performance and reliability. Disadvantages of zeotropic mixtures include the following:

Temperature glide — Because the composition a zeotrope alters during a phase change, there is a slight change in evaporating and condensing temperature at constant pressure. This phenomenon is known as "glide." Most zeotropic mixtures under consideration exhibit low glide. This phenomenon is a little different from similar effects seen with single-component refrigerants caused by normal pressure drop in the heat exchanger. As a result, little or no effect on system performance is expected.

Fractionation — since the components of a zeotropic mixture possess different vapor pressures, under some conditions they may leak from a system at different rates. As a result, the refrigerant composition may change over time, with a corresponding change in performance.

Zeotropic mixtures available in the marketplace with a glide of less than six degrees Fahrenheit (3.3 degrees Kelvin) approximate an azeotrope so closely that fractionation should not be a serious problem. The only exceptions to this are systems that use multiple evaporators or flooded evaporators.

To ensure fractionation does not occur during charging, it is recommended that zeotropic mixtures be liquid charged rather than vapor charged. Liquid must be removed from the refrigeration cylinder. It then can be flashed through a metering device and charged into the system in its vapor state. The refrigerant manufacturer's recommendation should be closely followed.

R-134a

R-134a is the first non-ozone-depleting fluorocarbon refrigerant to be commercialized. Developed more than 25 years ago to have characteristics similar to R-12, it is used in medium- and high-temperature applications in which R-12 had been used. R-134a is used in automotive air conditioning because of its low hose permeability and high critical temperature. Domestic refrigerator producers also use R-134a. R--134a is available from most refrigerant manufacturers.

R-134a has the benefit of being a single-component refrigerant and, therefore, does not have any glide. Also, the direct HGWP of R-134a is low.

The disadvantage of R-134a lies in its fairly low capacity compared to R-22. To use this refrigerant, all the tubing in the heat exchangers and between the components a system need to be significantly larger to minimize pressure drops and maintain an acceptable operating efficiency. Combined with the greater compressor displacements required, it results in a system that will be more costly than R-22 systems today. The heat-transfer coefficient of R-134a is also lower than that of R-22, and tests show that system performance degrades with its use.

This may not be the case in larger commercial systems, in which large screw or centrifugal systems are used, and refrigerants like R-11 and R-12 were common. Here, R-134a may offer the best solution for a fairly low-investment, simple redesign to HFCs.

Emerson laboratory and field trials show that the refrigeration capacity and energy efficiency of R-134a are similar to R-12 for medium- and high-temperature applications. At evaporating temperatures below -10 degrees Fahrenheit (-23 degrees Celsius), R-134a loses its attractiveness for several reasons:

- It experiences significant loss of capacity and efficiency compared to R-12.
- Pressure ratios become high, compromising compressor reliability.
- Low side pressures are sub-atmospheric (i.e., vacuum), resulting in system reliability concerns.

Except for ozone-depletion potential, Emerson believes that R-134a possesses the same deficiencies as R-12 and represents a step backward for most commercial refrigeration and air conditioning applications. These deficiencies include larger-displacement compressors and larger-diameter tubing compared to that required for use with high-pressure refrigerants.

For customers planning to use R-134a, Emerson has developed product lines for applications above -10 degrees Fahrenheit (-23 degrees Celsius) evaporator temperatures.

R-404A

Equipment manufacturers use HFC refrigerant R-404A as the long-term replacement for R-502. R-404A is an excellent low- and medium-temperature refrigerant, because of high energy efficiency and zero-ozone-depletion potential. R-404A is a near-azeotropic blend of HFC refrigerants R-125, R-143a and R-134a. It is commercially available from many sources and is becoming the most popular refrigerant of its class.

R-507

This refrigerant is an azeotropic mixture of R-143a and R-125, with characteristics also similar to R-502. Emerson compressors developed for R-404A (except for a few hermetic reciprocating models) are also approved for R-507. R-404A and R-507 operate at slightly higher pressures and slightly lower discharge temperatures than R-502.

R-407C

R-407C is a blend of R-32, R-125 and R-134a. Of the higher-temperature HFC options, R-407C was designed to have operating characteristics similar to R-22. The major concerns surrounding R-407C are in its high glide (10 degrees Fahrenheit) and the efficiency degradation when compared to R-22; however, this refrigerant provides the simplest conversion of the HFC alternatives. In systems where glide is acceptable, R-407C has become a popular option for manufacturers who want to move quickly to an HFC alternative. In the long run, however, the lower-efficiency performance of this refrigerant may make it a less attractive alternative when compared to R-410A for medium-and high-temperature applications.

Care should be taken when applying R-407C in any applications in which glide can impact system performance by fractionation in flooded-evaporator or multi-evaporator designs. Also, R-407C should not be viewed as a drop-in for R-22 systems or applications. Like all HFCs, R-407C requires POE lubricants, and other system design modifications may be required for R-407C to operate acceptably in R-22 systems.

R-407A

R-407A is a blend of R-32, R-125, and R-134a in a 20/40/40 ratio by mass. R-407A was designed for low and medium temperature refrigeration applications. With an IPCC4 GWP Value of 2107, R-407A has 54% lower GWP than R-404A. Manufacturers of this refrigerant claim a good capacity and efficiency match for R-22, making it well suited as a retrofit for R-22 in supermarket and food storage applications. Discharge temperatures of R-407A will be lower than R-22 but system pressures are higher. Compressor cooling should be taken into account for high ambient operation.

R-32

R-32 is an HFC refrigerant that is slightly flammable, with an ASHRAE 34 flammability classification of A2L. It is best known as a component in R-410A. R-32 is not currently being marketed as a stand-alone refrigerant in North America, but is gaining interest in China.

R-410A

R-410A has become the refrigerant of choice for use in residential air conditioning applications. Most major residential air conditioning manufacturers offer R-410A product lines. R-410A delivers higher efficiency and better TEWI than other choices. The refrigerant also has many benefits that make it an ideal refrigerant for use in commercial refrigeration applications.

There are several distinct operational differences between R-22 and R-410A refrigerants. R-410A operates at 50 percent higher pressure than R-22; however, the higher pressure allows the system to run at a lower temperature. Because of these differences, anyone handling these units should get training on the technical aspects of the new R-410A systems, where they can learn proper joint brazing and maintenance tips for this refrigerant.

R-410A is a near-azeotrope composition of 50 percent R-32 and 50 percent R-125. System testing has shown that R-410A delivers higher system efficiency than R-22. R-410A evaporates with a 35 percent higher heat-transfer coefficient and 28 percent lower pressure drop compared to R-22.

Other system performance enhancements have been gained by sizing for equal pressure drop and reducing the number of coil circuits needed to raise the mass flux. The higher density and pressure also permit smaller-diameter tubing, while maintaining reasonable pressure drops.

Because systems that use R-410A have been specially designed to use less tubing and fewer coils, R-410A has emerged as a cost-effective refrigerant. Fewer materials, along with lower refrigerant charge and better cyclic performance, also contribute to the affordability of R-410A.

R-410A is considered a high-pressure refrigerant. High-pressure refrigerants operate at pressures significantly higher than those normally seen with refrigerants such as R-22 and R-502. They cannot be used as retrofit refrigerants with existing equipment, but only in new equipment (including compressors) specifically designed for them. R-22 compressors cannot meet UL and industry design standards with these higher pressures.

For refrigeration application, R-410A is potentially the most efficient refrigerant at medium-temperature conditions (zero to 30 degrees Fahrenheit). Other advantages include smaller line sizes and lower pressure drops; however, the system would require design for higher pressures. Potential changes in UL requirements may reduce the impact. Testing at lower temperatures has shown promising results. Research is ongoing at Emerson to understand the benefits of this refrigerant in commercial refrigeration.

R-417A

R-417A was developed to be a "drop-in" refrigerant for new and service replacements of R-22, while using traditional HCFC lubricants, such as mineral oil and alkyl benzene (AB). This refrigerant is branded as ISCEON® 59 and Nu-22™ refrigerants and is a blend of R-125 (46.6 percent), R-134a (50 percent) and R-600 butane (3.4 percent). The hydrocarbon in the mixture was added to enhance oil return. ASHRAE designates the refrigerant as A1/A1 rated, meaning that it is nontoxic and nonflammable. The refrigerant manufacturer claims equivalent capacity and improved efficiency compared with R-22. It further claims that R-22 lubricants can be maintained, but recommends a consultation with the system and compressor manufacturer for current recommendations.

The manufacturer's claims about R-417A performance are not supported by independent test reports. Independent testing of R-417A has shown between nine and 10 percent lower system capacity when used as a drop-in refrigerant. This same testing shows efficiency losses of three to five percent. Independent testing of R-417A has also shown significant delays oil return.

Two more challenges are presented with R-417A. The refrigerant has a worse GWP rating than R-407C and R-22. As a blend, R-417A has the same fractionation and glide issues as R-407C. So a system leak may affect the composition significantly and, therefore, the properties of this refrigerant.

Emerson Climate Technologies does not expect R-417A to be a significant HFC alternative to R-22. Refrigerant R-417A has neither been fully tested nor qualified by Emerson and at this time is not approved for use in our compressors or components.

R-152a

R-152a is chemically similar to R-134a, but it is different environmentally. R-152a has a much lower GWP (120 compared to 1,300) than R-134a but is considered ASHRAE A2 — flammable.

R-152a is being considered as an option to replace R-134a in automobile air conditioning; however, because of its flammability, R-152a is not a serious alternative for commercial refrigeration systems.

R-422 refrigerants

R-422A, R-422B and R-422D are other HFC refrigerants that were developed for replacement of R-22. All R-422 series refrigerants have the same blend of refrigerants. The last letter simply signifies slightly different percentages of the refrigerant mixes. R-422 refrigerants are branded as One Shot™ or ISCEON 9 series and are a blend of R-125 (85 percent), R-134a (11.6 percent) and R-600a (3.4 percent). The hydrocarbon in the mixture was added to enhance oil return. The refrigerant manufacturers claim equivalent capacity and improved efficiency compared with R-22. They further claim that R-22 lubricants can be maintained, but recommend a consultation with the system and compressor manufacturer for current application considerations.

Independent testing of R-422A has shown that its capacity is 10 to 15 percent lower than R-22 and R-404A, especially in low-temperature conditions. Mass flow of R-422A is even higher than R-404A and about 55 percent higher than R-22. Pressures of R-422A are similar to those of R-404A and 20 percent higher than R-22.

Refrigerant changeover guidelines are available from Emerson that describe the retrofit procedures when transitioning from R-22 to R-422 series refrigerants.

Future low-GWP fluorocarbon refrigerants

Several refrigerant manufacturers are developing refrigerants for automotive air conditioning applications that will meet European Union environmental standards for GWP substances. The most likely candidate to replace R-134a in automotive air conditioning applications is HFO-1234yf, a single-component refrigerant with a much lower GWP than R-134a. These future low-GWP refrigerants are being developed as non-carbon dioxide alternatives. Other possible fluorocarbon refrigerants under development are two-blend azeotropes with HFO and R-32 or R-134a.

Halogen-free refrigerants

Ammonia

Ammonia (NH3) is widely used as a refrigerant in large industrial refrigeration plants. As a halogen-free refrigerant, ammonia has the benefit of zero-ozone depletion potential and no direct GWP; however, its high toxicity limits its application to industrial refrigeration applications. In large ammonia systems, the efficiency is the same as similar systems with R-22 refrigerant.

Although ammonia is widely available and is a low-cost substance, there are significant challenges to applying ammonia as a refrigerant in commercial refrigeration systems. Ammonia systems have higher discharge pressures than R-22. Oil management becomes a major issue in ammonia systems, since the oils used are usually not soluble in ammonia. The low mass flow of ammonia compared to R-22 is an advantage for large ammonia plants, but becomes a challenge in smaller commercial systems. Also, ammonia is highly corrosive on copper materials, so refrigerant lines must be steel, and the copper in the compressor-motor windings must be insulated from the gas.

The major drawback of using ammonia in commercial refrigeration applications is its high toxicity and flammability level. This alone requires unique safety measures that are well beyond the scope of most commercial installations.

Carbon dioxide

Environmental concerns about the potential direct emissions from HFC-based refrigeration systems have led to legislation and taxation schemes in parts of Europe that favor the usage of carbon dioxide (CO_2) as a refrigerant. CO_2 is given the designation R-744. CO_2 is environmentally benign compared with other refrigerants, is nonflammable, has low toxicity, is widely available and is a low-first-cost substance. These are the reasons it was one of the original refrigerants, used nearly 100 years ago. Although thermodynamic performance of a simple CO_2 cycle is poor — 30 to 50 percent worse than HFCs — “poor” refrigerants such as CO_2 tend to have good heat-transfer characteristics and respond well to cycle modifications.

Many CO_2 systems are designed for transcritical operation. These systems tend to have lower energy efficiency, compared to conventional systems, and the system design is different from conventional systems. Transcritical operation means that the CO_2 does not condense at the high pressure, and rather than using using a traditional condenser, a gas cooler is used. The pressures created by CO_2 present significant challenges in its usage. High side pressures are about 2,500 pounds per square inch (psi), and excursions can go to 4,000 psi. This is a technical and cost challenge not only for the compressor, but also for the heat exchangers.

Typical cycle efficiency is 40 percent of the ideal refrigeration cycle Carnot15, where the Coefficient of Performance (COP) is 2.5, compared with 68 percent (COP 4.2) for an R-134a system at high-temperature conditions. Microchannel heat exchangers, gas/suction heat exchangers or CO_2 expanders improve system performance, with some added cost and complexity.

The cost impact of CO_2 in transcritical systems is substantial. Because of the higher pressure, modifications are required on the compressor shell, valves, rings, terminal and seals, and the pressure relief valve and microchannel heat exchanger. Performance implications require CSHX, a discharge-pressure regulator valve and a low side accumulator to control excess charge. Another oil separator is required because of oil circulation and return problems. The bottom line is a 20 to 30 percent higher final cost for performance levels equal to those of an HFC.

The comparably high pressure level and thermodynamic properties of CO_2 as a refrigerant have driven system designers to consider subcritical CO_2 systems. These systems operate much like conventional cascade refrigeration systems. In a subcritical system, CO_2 is used as a direct expanding medium in the low-temperature stage, and different options exist for the medium-temperature stage. This way compressors in the low-temperature stage are only exposed to pressure levels similar to high-pressure air conditioning applications, such as with R-410A. Subcritical operation might be the best application of CO_2 as a refrigerant for some commercial refrigeration applications.

In summary, CO_2 has many technical and cost challenges. The low efficiency and cycle complexity are the main limitations; however, CO_2 may become used in transport and low-temperature cascade systems, and in some heat-pump applications. Whether transcritical or subcritical CO_2 systems are considered, CO_2 technology cannot be seen as a drop-in replacement for any of the other refrigerants mentioned in this paper. Any application of CO_2 requires a thorough assessment of system efficiency, TEWI, life-cycle cost, technical feasibility, reliability and safety.[9]

Hydrocarbons

The push for halogen-free refrigerants has led manufacturers to investigate hydrocarbons as a replacement for R-22. Propane (R-290) is considered as a replacement, because it is a halogen-free substance with no ozone-depletion potential and low direct GWP. Propane is widely available and is a low-cost substance. The operating pressures of a refrigeration system with propane are similar to R-22. Propane has been applied in systems with low charge — less than 150 grams (10 ounces) — and often outside the U.S.

The disadvantage of propane and all hydrocarbons is that they are highly flammable. System costs are higher because of the required safety measures. Special considerations must be taken for excess pressures and electrical connections, and ventilation to prevent flammable gas mixtures. Commercial operators do not want to risk the safety-code issues and litigation risks associated with using propane in a refrigeration system.

The refrigeration industry is anticipating U.S. EPA SNAP approval of R-290 Propane refrigerant for Domestic refrigerators and small self-contained Commercial Refrigeration equipment soon. Also, several Foodservice operators and OEMs are exploring the performance and economics of transitioning refrigeration applications to HFC-free, or 'natural' refrigerant alternatives over the next several years, both in the U.S. and globally. The primary benefits of these transitions would be to:

- Reduce the Direct Global Warming Potential (GWP) of the refrigerant to near zero to significantly mitigate the refrigerant's impact on global climate change
- Potentially improve equipment energy efficiency to cut the Indirect GWP of CO_2 emissions generated during electricity production, while using less electricity.
- Employ 'renewable' refrigerant gases which are by-products of various processes, thus generating a lower cost and lower carbon footprint refrigerant than today's manufactured alternatives

The most common natural refrigerant alternatives being considered for small commercial refrigeration applications are R-290 Propane and CO_2, while new slightly flammable (A2L Class) chemical blends (i.e., HFO1234yf) are being considered as future low GWP options. China is also evaluating an A2L alternative known as R-32 (a component of R-410A).

Emerson Climate Technologies supports initiatives to apply alternate refrigerants and is maintaining several R&D and Engineering programs. To date, Emerson has been involved in selection and application of R-290 Propane compressors and condensing units which have been tested and applied in UL 471 approved systems and prototype equipment designs requiring 150 grams or less of propane refrigerant.

While propane refrigerant can be safely applied in selective applications by following specific industry guidelines and safety practices associated with flammable substances, its use for commercial refrigeration in the United States is untested and is not yet EPA approved.

System design considerations

Emerson has worked with many refrigerant companies to ensure that new refrigerants are compatible with new Emerson components used in the refrigeration industry. Older components may not be compatible with the new refrigerants and oils, especially those that have been operating in the field for more than a decade. Before retrofitting any system, check the manufacturer's recommendations.

Lubricants

Most manufacturers of hermetic and semi-hermetic compressors have determined that POEs are the best choice of lubricants for use with HFC refrigerants. Besides providing superior lubrication with the new refrigerants, POE oil has other advantages that make it attractive for use in refrigeration.

Because POE oil can be used with all refrigerants and is backwards compatible with mineral oils commonly used with CFCs and HCFCs, it offers the most flexibility in dealing with the uncertainties imposed by the CFC issue. For example:

- Using POE oil in a new HCFC system will allow the easy transition to HFCs, without the expensive, repetitive flushing procedure needed to remove the mineral oil from the system.
- During system service, if POE oil is used to replace any mineral oil removed from a system, it starts the process to flush the system of mineral oil, so that conversion to an HFC can be performed with fewer steps later.
- POE oil can also be used with the intermediate HCFC mixtures if they are used to replace CFCs. A mixture of at least 50 percent POE oil in mineral oil provides excellent lubrication and will start the flushing procedure if a switch to HFCs occurs.

Regardless of which HFC refrigerant an OEM is considering, care must be taken in the design and handling of systems using these new refrigerants. Although they provide an ozone-friendly solution to the industry, HFCs do present new challenges.

POE oils are an important requirement to ensure the reliability of the compressor when used with HFCs; however, when using POE oils, care must be taken to keep the oil dry, because of its hygroscopic characteristics. Proper precautions must be taken in the manufacturing of the system and its ultimate installation in the field, to prevent excess moisture from entering the system. A properly selected filter drier is strongly recommended.

R-410A and R-407C are blends and, therefore, exhibit glide characteristics. The impact of glide must be considered both in the system design and in servicing the system. Manufacturers must understand and convey to the field the impact of leaks on non-azeotropic mixtures. Systems containing a non-azeotropic refrigerant must be liquid charged to ensure that the proper component mixtures are added.

R-410A refrigerant has higher operating pressures and is significantly different from R-22; therefore, R-410A systems require special considerations to increase performance and benefits of the refrigerant. Precautions must be taken to ensure that the heat exchangers and components being used are designed to handle these higher pressures. R-410A has a much lower critical temperature (162.5 degrees Fahrenheit, compared to 204.8 degrees Fahrenheit for R-22) which must be considered when using this refrigerant in units designed for high ambient applications.

Compressors

As system manufacturers consider new equipment designs to operate with HFC refrigerants, they are impacted by many other changes occurring throughout the industry, including several approved and proposed energy-efficiency regulations. New ASHRAE standards mandate increases in efficiency levels across a variety of commercial equipment. New state and federal energy efficiency standards, along with various incentive programs, drive OEMs to periodically redesign many of their refrigeration products.

Over the past decade, Emerson has developed and released a series of new scroll models to support the industry's need for chlorine-free systems. Many products are designed to operate with R-404A, R-134a, R-407C or R-410A. There is a wide variety of displacements available for most commercial refrigeration applications.

This shows the unique flexibility of scroll technology, with its inherent ability to adapt to higher-pressure refrigerants like R-410A and more standard-pressure refrigerants like R-407C. Although the design challenge is serious, scrolls are more easily adapted to higher pressures and are more efficient than other compressor technologies. Most reciprocating designs will require extensive retooling and redesigning to handle the higher pressures.

System protection

- **Filter driers**

  Filter driers available are compatible with the new refrigerants and lubricants, as far as materials are concerned. The filter drier must be solid core or compacted bead (spring loaded). The desiccant must be tested to ensure compatibility with the new refrigerants and lubricants. Filter Driers from Emerson with a maximum of 30 percent activated alumina, is designed for this specific purpose. These are available as hermetic filter driers and as replaceable core-type products.

  Activated alumina is used in filter driers to remove acids from the system. POE oils exposed to excessive moisture may hydrolyze and produce acids; therefore, small amounts of alumina are used in filter driers recommended with POE oils. Molecular sieve filter driers are the best for moisture absorption. With the hygroscopic POE oil lubricants, it is important that the filter drier have a high moisture-absorbing capability. Oversized filter driers may become the standard.

  For more information on the EK Filter Drier, please reference the Appendix.

- **Pressure-control valves**

  Many new refrigerants have higher pressures; thus, all pressure controls and pressure-operated valves may need to be reset for proper operation. Some of the controls or valves may even need to be replaced. Pilot-operated valves must be checked to be sure they are operating properly. The pilot-operated valve, in many cases, requires a minimum pressure differential to open, and the valve will not operate properly unless this pressure differential is correct. Valves or controls may also need to be resized. Other system components will also be affected by the new refrigerants and lubricants. Consult your equipment manufacturer for guidelines and more information.

- **Viewing lens/moisture indicator**

  Moisture indicators on refrigeration equipment provide early warning to the long-term effects of water damage and cut repair and maintenance costs. The proper moisture indicator must sense and report just how much water is in the system's circulating refrigerant. An indicator in a sight glass changes color as the moisture content reaches potentially damaging levels. Be sure to choose an indicator that is sensitive enough to alert operators early on that moisture levels are rising, allowing corrective action to be taken before serious system damage occurs.

Moisture Indicators from Emerson (HMI, AMI and MIA) are able to read moisture levels far below industry standards. These indicators start to change color at two percent relative humidity (RH), which is a "very dry" indication. At three percent RH, the purple caution color starts to appear. Many other indicators do not start changing colors until about seven to eight percent RH; however, early detection is critical with HFC refrigerants and POE lubricants. POE oil can hold up to 20 times more moisture than the mineral oil used by older refrigerants, which can allow corrosive acids to build up and totally destroy a system.

- **Liquid-control device**

The liquid-control or metering device may be a capillary tube or a thermal expansion valve, and controls the flow of refrigerant to the evaporator. The liquid-control device will not have to be changed when an R-502 system is retrofit with R-402A, R-408A, R-404A or R-507. Although the capacity of the liquid-control device is almost the same, the flow capacity of the liquid-control device in an R-12 system may increase up to 30 percent with the new refrigerants.

When an R-12 system is retrofitted with either an HCFC blend or R-134a, the liquid-control device may have to be changed; however, a properly sized R-12 expansion valve may work with the new refrigerant by adjusting the evaporator superheat. The capillary tube can, in all probability, be made to work with the new refrigerant by adjusting the refrigerant charge. Although most systems can be retrofitted without changing the liquid-control device, the valve superheat or the system charge must be adjusted. Systems using expansion valves still require a solid column of liquid refrigerant at the expansion-valve inlet.

Service considerations

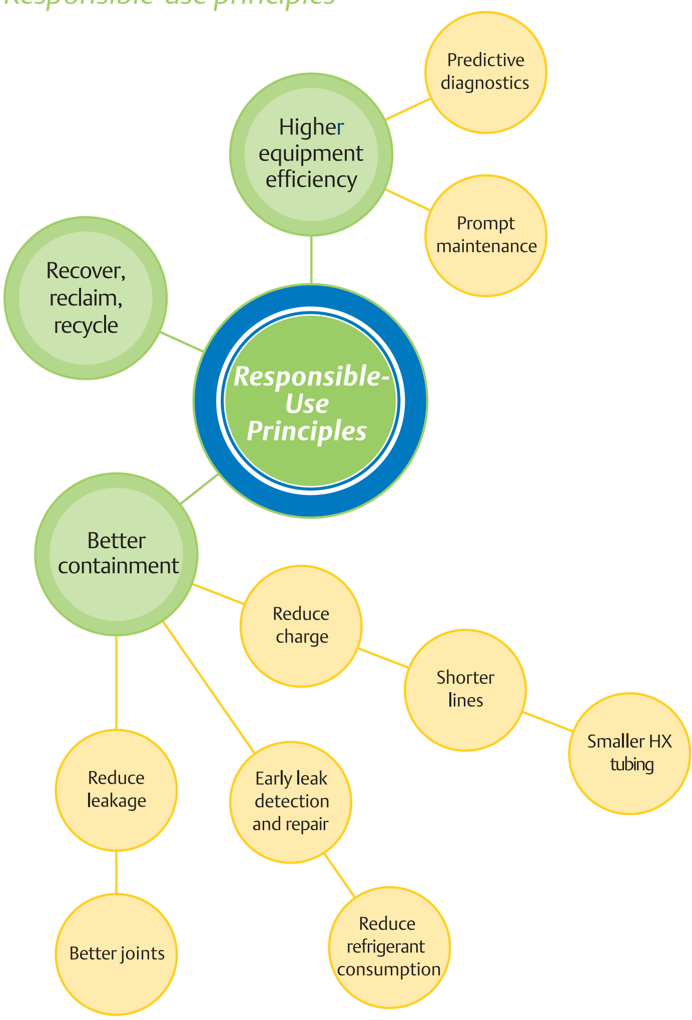
Responsible-use principles

Emerson promotes the idea that responsible use is the key to safety and environmental stewardship. As already discussed, HFC refrigerants are the key to energy-efficient refrigeration equipment. But other factors also figure into optimized energy efficiency (see **Figure 5**). Prompt maintenance is important to keeping systems running not only longer, but also more efficiently. Preventive maintenance routines can help extend the life of equipment and increase energy efficiency.

Containment is one way to promote the responsible use of refrigerant. Equipment manufacturers are working to design systems that require less charge and have fewer leaks. There can be no direct impact on the environment from any refrigerant that is in a well-designed system. Early leak detection and repair will reduce refrigerant consumption. All refrigerants should be recovered, reclaimed and recycled at the end of the system life.

Emerson Climate Technologies developed its ProAct™ Refrigerant Management service to help equipment owners maintain compliance with the EPA's Clean Air Act. The service organizes refrigerant-related inventory information quickly and easily, lowering refrigerant loss due to leaks or

Responsible-use principles



Endorsed by: U.S. EPA, MITI, UNEP, ARI, ACCA, AHAM, The Alliance and 25 others

Figure 5

reduction of inventory. By providing all the proper documentation, Emerson helps operators close the loop between the technicians and the owners who have the responsibility for compliance. The service provides electronic access to all refrigerant data for management, analysis and reporting purposes, alleviating many hassles and omissions associated with paper tracking.

Responsible use of refrigerants[10]

- Contain refrigerants in tight or closed systems and containers, lowering atmospheric releases.
- Encourage monitoring after installations to lower direct refrigerant emissions and to maintain energy efficiency.
- Train all personnel in proper refrigerant handling.
- Comply with standards on refrigerant safety, proper installation and maintenance (ASHRAE-15, ISO-5149 and European Standard EN378).
- Design, select, install and operate to increase energy efficiency.
- Recover, recycle and reclaim refrigerants.
- Continue to improve equipment energy efficiency when cost effective.

Future direction

The next generation of refrigerants has been established. As reviewed here, HFCs have low-ozone depletion advantages over R-22; however, they still have some GWP.

It is important to recognize that this is an evolutionary process. Today's HFCs are the next steps, but they are not the last steps in the process. As technologies develop and new applications and system designs continue to emerge, other refrigerants may be developed and applied.

No HFC refrigerant can cause direct global warming if it is properly contained. In the HVACR industry and in others, we expect to see more emphasis on refrigerant recovery and leak prevention in the coming years. As the concern over potential climate change grows, Emerson Climate Technologies will continue to work closely with refrigerant and system manufacturers, industry organizations and approved regulations to improve compressor performance, efficiency and reliability, while reducing environmental impact.

Glossary of terms

Azeotrope: A blend, when used in refrigeration cycles, that does not change volumetric composition or saturation temperature appreciably as it evaporates (boils) or condenses at constant pressure.

Blend: A refrigerant consisting of a mixture of two or more different chemical compounds, often used individually as refrigerants for other applications.

CFC refrigerant: A chlorofluorocarbon, containing chlorine, fluorine and carbon molecules (CFC R-12).

Fractionation: A change in composition of a blend by preferential evaporation of the more volatile component(s) or condensation of the less volatile component(s).

Glide: The difference between the starting and ending temperatures of a phase-change process by a refrigerant (at constant pressure) within a component of a refrigerating system, exclusive of any subcooling or superheating. This term is usually used in describing the condensation or evaporation process.

GWP: Global Warming Potential. This is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale that compares the gas in question to that of the same mass of carbon dioxide, whose GWP is 1.0.

Halogen-free refrigerant: A refrigerant that does not contain halogen compounds, such as chlorine and fluorine (hydrocarbons, ammonia). This is also commonly referred to as a "natural refrigerant," since it is found in nature.

HCFC refrigerant: A hydrochlorofluorocarbon, containing hydrogen, chlorine, fluorine and carbon molecules (HCFC R-22).

HFC refrigerant: A hydrofluorocarbon, containing hydrogen, fluorine and carbon molecules (HFC R-134a).

HGWP: Halocarbon Global Warming Potential. This is similar to GWP, but uses CFC-11 as the reference gas, where CFC-11 is equal to one (GWP for R-11 - 4,000).

Near-azeotrope: A zeotropic blend with a small temperature and composition glide over the application range and no significant effect on system performance, operation and safety.

Pure compound: A single compound, which does not change composition when changing phase.

Total Equivalent Warming Impact (TEWI): TEWI integrates the global warming impacts of equipment's energy consumption and refrigerant emissions into one number, usually expressed in terms of CO_2 mass equivalents. The calculated TEWI is based on estimates for (1) the quantity of energy consumed by the equipment over its lifetime; (2) the mass of CO_2 produced per unit of energy consumed; (3) the quantity of refrigerant released from the equipment over its lifetime; and (4) the GWP of that refrigerant, expressed in terms of CO_2 mass equivalent per unit mass of refrigerant.

Zeotrope: A blend, when used in refrigeration cycles, that changes volumetric composition and saturation temperatures to varying extents as it evaporates (boils) or condenses at constant pressure.

Appendix

For more information, the following materials are available from Emerson on our online product information (OPI) website, **EmersonClimate.com**:

Introduction to Refrigerant Mixtures, form number 92-81

Emerson Climate Technologies, Inc. Accepted Refrigerants/ Lubricants, form number 93-11

R-134a, Application Engineering Bulletin AE-1295

Application Guidelines for ZP**K*E Scroll Compressors for R-410A, Application Engineering Bulletin AE-1301

Refrigerant Changeover Guidelines

(CFC) R-12 to (HCFC) R-401A 93-02

(CFC) R-12 to (HCFC) R-401B 93-03

(CFC) R-12 to (HFC) R-134a 93-04

(CFC) R-502 to (HCFC) R-402A/408A 93-05

(CFC) R-502 to (HFC) R-404A/R-507 94-15

(HCFC) R-22 to (HFC) R-407C 95-14

(HCFC) R-22 to (HFC) R-404A/R-507 2005CC-54

Access the EK Filter Drier and HMI white papers at **EmersonClimate.com**.

References

1 According to Annika Nilsson in her book Ultraviolet Reflections: Life Under A Thinning Ozone Layer, related diseases may include skin cancer and cataract formation. (Chichester: John Wiley & Sons Ltd., 1996)

2 www.epa.gov/climatechange/

3 http://www.eia.doe.gov/oiaf/ieo/emissions.html

4 http://ozone.unep.org/teap/Reports/TEAP_Reports/teap-2010-progress-report-volume1-May2010.pdf

5 EPEEGlobal.org , EPEEs FAQ on the F-Gas Regulation

6 The scope of UL Standard 2182.1 contains test procedures and methods to evaluate refrigerants and mark their containers according to the extent of the refrigerants' flammability.

7 TLV minus TWA presents a standard for limiting worker exposure to airborne contaminants. These standards provide the maximum concentration in air at which it is believed that a particular substance will not produce adverse health effects with repeated daily exposure. They are expressed either as parts per million (ppm) or milligrams per cubic meter (mg/m3).

8 The Alliance for Responsible Atmospheric Policy, http://www.arap.org/print/docs/responsible-use.html

9 ASERCOM statement, Carbon Dioxide (CO_2) in Refrigeration and Air-Conditioning Systems (RAC), June 2006.

10 http://www.arap.org/responsible.html

About Emerson

Emerson (NYSE:EMR), based in St. Louis, Missouri (USA), is a global leader in bringing technology and engineering together to provide innovative solutions for customers in industrial, commercial, and consumer markets through its network power, process management, industrial automation, climate technologies, and appliance and tools businesses. Sales in fiscal 2009 were $20.9 billion. For more information, visit www.Emerson.com.

About Emerson Climate Technologies

Emerson Climate Technologies, a business of Emerson, is the world's leading provider of heating, air conditioning and refrigeration solutions for residential, industrial and commercial applications. The group combines best-in-class technology with proven engineering, design, distribution, educational and monitoring services to provide customized, integrated climate-control solutions for customers worldwide. The innovative solutions of Emerson Climate Technologies, which include industry-leading brands such as Copeland Scroll and White-Rodgers, improve human comfort, safeguard food and protect the environment. For more information, visit EmersonClimate.com.

About Emerson Climate Technologies, Inc.

Emerson Climate Technologies, Inc., part of Emerson Climate Technologies, is the world's leading compressor manufacturer, offering more than 10,000 compressor models in a full range of technologies, including scroll, reciprocating and screw compressor designs. A pioneer in the HVACR industry, the company led the introduction of scroll technology to the marketplace. Today more than 56 million Copeland Scroll™ compressors are installed in residential and commercial air conditioning and commercial refrigeration systems around the world. Emerson Climate Technologies, Inc. is headquartered in Sidney, Ohio. For more information, visit EmersonClimate.com.

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