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CONDENSER

What's NEXT:

LESSONS FROM CALIFORNIA'S HFC PHASEDOWN

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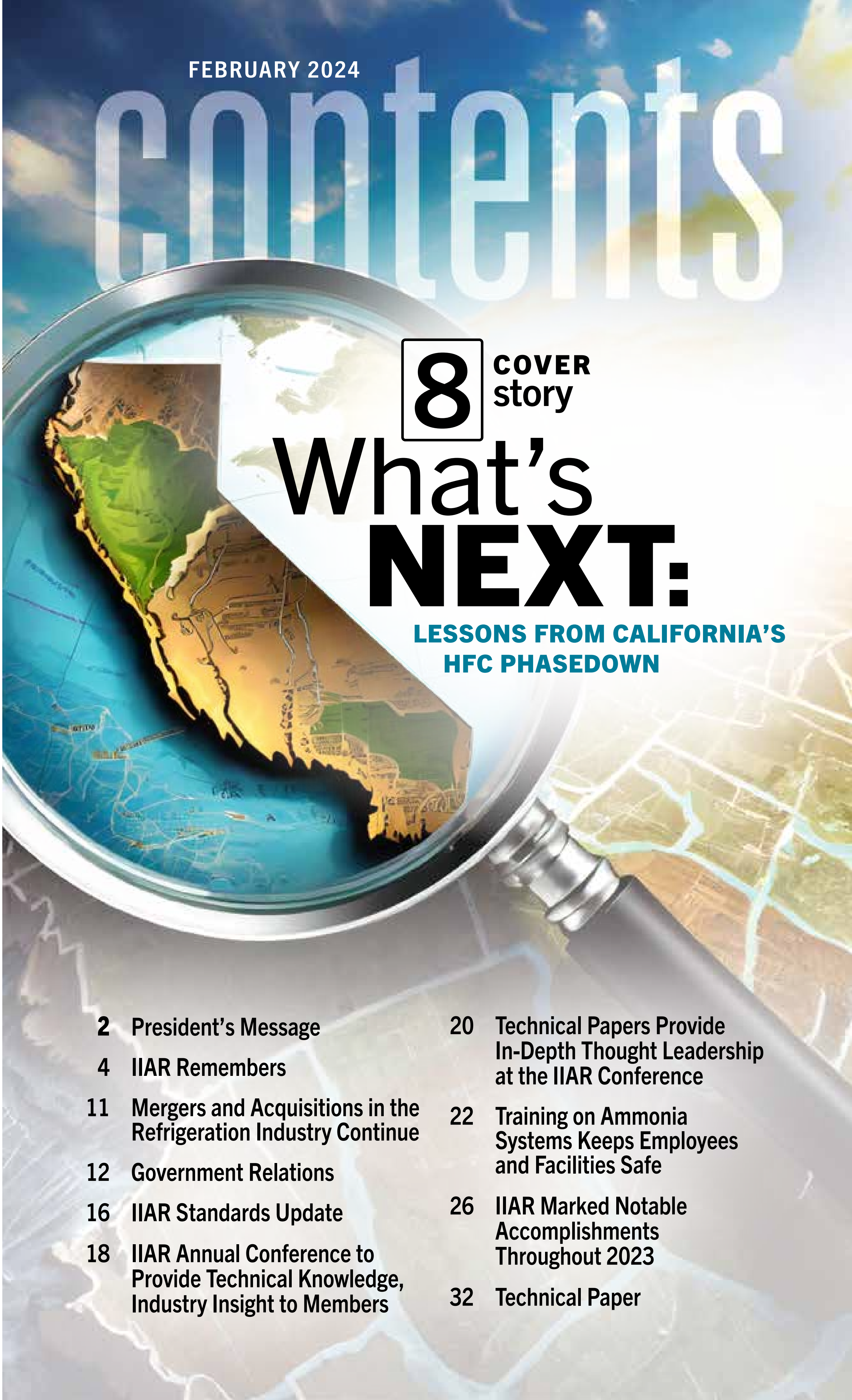

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What's NEXT:

LESSONS FROM CALIFORNIA'S HFC PHASEDOWN

president's MESSAGE

BY GARY SCHRIFT

It's IIAR conference time again, which means immediately following the March Conference, in April 2024, it will be time to begin the membership renewal process for the 2024-2025 IIAR Membership year which runs from July 2024 through June 2025. I invite you to renew your IIAR membership and continue to receive into the next year all of the many new and expanded benefits provided for you and your co-workers. I am always in awe of the volume of work our organization turns out through the dedicated work of our many volunteers and the IIAR staff – and we've made significant strides in the last year through the dedication and commitment of members like you.

In this condenser issue, we've put together a detailed report to membership and future members discussing all the new ways IIAR provides operational resources, technical support, and networking opportunities in your professional life. Some of the highlights include:

ORGANIZATIONAL ENHANCEMENTS

IIAR underwent a complete rebranding and name change from the International Institute of Ammonia Refrigeration to the International Institute of All-Natural Refrigeration. As part of the rebranding effort, IIAR's marketing efforts included producing new IIAR and ARF videos, updating websites for IIAR and ARF, and increasing IIAR's digital marketing across social media platforms and Google. Organizational improvements included adding two new staff members, completing association management software and systems upgrades, and moving IIAR publications order and delivery services to a third party publishing platform that provides all publications, per the buyer's choice, in either print-on-demand hardcopy or a digital (ePUB) format readable using a full eService eReader platform.

OUTREACH TO NEW MEMBERSHIP

IIAR leadership will appear at several new conferences, including ASHRAE, the Ice Rink Association, the IIR Gustav Lorentzen conference on Natural Refrigerants and many other events. A new IIAR chapter in Brazil and new Memorandums of Understanding (MOUs) with the UK-based Institute of Refrigeration, the French International Institute of Refrigeration (IIR), and the North American Sustainable Refrigeration Council (NASRAC) have expanded IIAR's presence nationally and internationally.

ANNUAL CONFERENCE

The IIAR annual conference continues to be one of the organization's most popular member benefits, and the conference saw several milestones in 2023, including a first-ever sold-out conference exhibit hall for the 2024 conference. Among other improvements is a newly implemented "A to Z" exhibit sales and sponsorship sales software system, which replaces the old exhibitor priority system for exhibit sales. A newly instituted VIP event for IIAR board and committee members, , an NRF fun day hosting all of the Natural Refrigeration Foundation (NRF) tournaments, an IIAR student day, and a RETA in-person Certified Refrigeration Technician Training program will be updated features of the 2024 conference.

MISSION ACHIEVEMENTS

IIAR met several specific goals in 2023, pushing forward with standards developments and updates, educational resources, and advocacy. Highlights included creating an IIAR Condenser Magazine website housing over 500 now internet searchable magazine articles dating back to 2009 a well-marketed NRF scholarship program that yielded 30 applicants in 2023, with eight awarded scholarships. Meanwhile, IIAR successfully influenced the AIM Act's final ruling for technology transition and joined the United Nations Environment Programme's Cool Coalition.

> When you belong to the IIAR community, your voice matters. I'm looking forward to working with you again this year, and I invite you to renew your membership.

As always, I encourage everyone to participate in IIAR on our various volunteer committees and to take advantage of the many new member benefits coming your way this year. When you belong to the IIAR community, your voice matters. I'm looking forward to working with you again this year, and I invite you to renew your membership. We expect membership renewal for the 2024-2025 membership year to open up in April 2024.

IIAR Remembers

Roger McMillan

Colmac Coil Manufacturing CEO and Second Generation Owner

Roger McMillan, father of Colmac Coil Manufacturing's current CEO and Owner, Scott McMillan, passed away in December at 81.

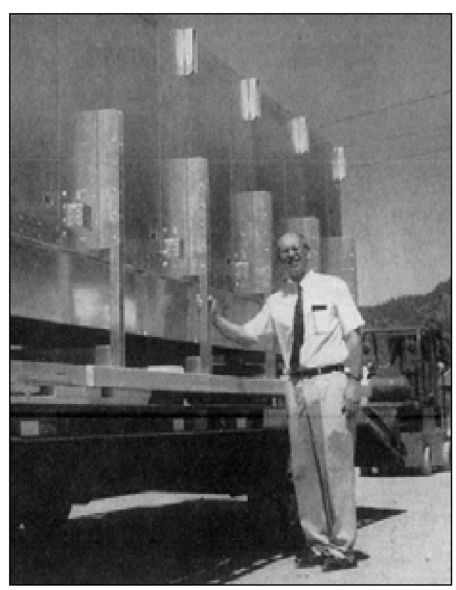
BY JOSEPH SCHWEITZER, MARKETING MANAGER, COLMAC COIL

Roger was born in Missoula, Montana, to Jerry and Gwen McMillan. He spent his early childhood in Spokane, Washington, and then Jerry and Gwen relocated their dry-cleaning business to Colville, Washington, where Jerry invented specialized laundry machines and started the Colmac businesses.

After Roger earned a Master of Science in Mechanical Engineering in 1966 at Washington State University, he spent two years in the US Army as a 2nd and 1st Lieutenant in the Ordinance Corps stationed at Ft Dix, NJ. Roger and his wife, Dee, returned to Colville, where Roger started working in engineering and product development at Colmac Industries.

Through the years, Colmac earned a reputation for using technology to propel its business forward, and Roger was at the center of that development. Since laundry machines are tough on coils and regular HVAC coils were not holding up, Jerry McMillan decided to build his own. He asked Roger to design a building, and within a year, Colmac Coil Manufacturing was building coils in a new 10,000 sq. ft. plant across the street from Colmac Industries.

In less than 20 years, the new company surpassed Colmac Industries in size. In 2007, Colmac Coil won the Washington State World Trade Club's "Emerging Trader of the Year" award, over 40 years after Jerry won the same (later renamed) award.



Roger was only 32 at the time of Jerry McMillan's passing, and with no succession plan in place, Colmac managers and employees kept moving forward.

From 1974 to 2002, Roger led Colmac Industries and Colmac Coil as CEO and Owner. During this time, Colmac Coil Manufacturing grew from a small manufacturer of steam coils to a much larger company with a product portfolio including heating and cooling coils, heat pipe coils, dry coolers and condensers, and industrial air coolers.

Under Roger's leadership, Colmac Coil Manufacturing developed its ability to engineer a wide range of heating and cooling solutions for the commercial and industrial markets.

"In 1981, Roger took a chance hiring a young engineer (yours truly), recently graduated from his Alma Mater, Washington State University," said Bruce Nelson, past president of Colmac Coil Manufacturing. "I quickly learned that Roger, like his father Jerry McMillan, loved to innovate and develop new products and then to travel to where the customers were to sell them — wherever that might be in the world. I feel very grateful to have worked first for Roger, and then Scott, for 40 years of my working life getting to do those very things."

"I have many good memories of my interactions with Roger, talking about new products and markets, and some amazing travel experiences with him. I also appreciated my personal interactions with Roger and his concern for the well-being of all of us as Colmac employees."

"When he first arrived in 1969, there wasn't a single drawing for any product," said Scott McMillan, CEO and owner of Colmac Coil Manufacturing. "He built a new team of drafters and later brought in computer-aided drafting and CNC machinery to modernize both businesses and develop the first "CoilPro" software sizing and selection models beginning in 1981."

After passing the executive management responsibilities to his son, Scott McMillan, in 2002, Roger was continually active in his church life and also golf and hiking while spending his summers in Colville and winters in Palm Desert, California.

"Roger occasionally stopped by the Colmac Coil factories to see the latest and greatest products on the manufacturing floor and to discuss what next products we were developing," said Joe Fazzari, President of Colmac Coil Manufacturing. "All of us will greatly miss Roger's presence, but his legacy will live on with every shipment of the high quality, engineered-to-order products we produce."

What's NEXT:

LESSONS FROM CALIFORNIA'S HFC PHASEDOWN

Companies nationwide are phasing out high global-warming potential refrigerants as they comply with federal and state regulatory requirements and meet their corporate ESG and climate goals. The natural refrigerant industry is prepared to meet increasing demand.

"Major OEMs are saying, 'We're ready. We're excited. Let's move forward," said Tristam Coffin, co-founder of Effecterra and president of sustainability, policy and technical services. "I can tell you that in both commercial and industrial, the transition to alternative refrigerants is possible."

California has been a leader in restricting the use of hydrofluorocarbons, and many in the industry are looking at regulatory requirements and transitions there in anticipation of what the rest of the U.S. will look like as the Environmental Protection Agency's AIM Act is finalized.

"The AIM Act technology transition and proposed refrigerant management rules reflect what you've seen California do. While California, in a lot of respects, has looked to the European Union for guidance," Coffin said.

THE GOLDEN STATE

California is approaching the HFC phase down from multiple angles. "They were the first state to set a 150 GWP limit on new systems. They were also the first state to set a GWP threshold for existing grocery stores requiring food retail systems >50 lbs. to meet <1400 GWP or equivalent limit by 2030," said Danielle Wright, executive director of the North American Sustainable Refrigeration Council.

In passing SB 1206, California became the first state to institute a ban on selling and distributing virgin HFC refrigerants. "Under the same bill, the state has also established a goal to transition the state away from HFCs and to ultra-low GWP alternatives no later than 2035," Wright said.

Starting Jan. 1, 2025, SB 1206 will prohibit the sale of virgin and new bulk HFCs with >2,200 GWP. From there, the prohibited threshold will drop to >1,500 in January 2030 and >750 in January 2033.

By 2025, the California Air Resources Board will assess how the transition is going. "Within the next year, we should see that assessment report, which will likely lead to more regulations," Coffin said, adding that officials in California have been upfront about their intentions to do more at the state level to achieve their climate objectives.

Other states have followed California's lead. "Washington's rule has gone into effect," Coffin explained. "They're launching their program now and leaning on the California Air Resources Board's work."

New York's latest proposal came out earlier this year and is even stricter than California's, Coffin said.

"Many states have learned from California's experience that mid-GWP refrigerants like R-448a and R-449a are short-term solutions. States like Washington and New York have sent strong market signals by structuring their regulations to leap-frog this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interim step and push food retailers to adopt <150 GWP solutions as soon as possible," Wright said.

Coffin added that the European Union has adopted new regulations to phase down fluorinated gases (F-gases). Under the new rules, HFC consumption will be completely phased out by 2050 and production of HFCs will be phased down to a minimum (15%) as of 2036.

"That takes the conversation from a phasedown of HFCs to a phase-out of fluorinated gasses. That is a trigger to the rest of the world that it is time to get us out of this circle of transitioning from one synthetic gas to another to another," Coffin said. "The most logical solution is natural refrigerants."

COMMERCIAL AND INDUSTRIAL ADOPTION

Many in the commercial sector are preparing to meet requirements and have shifted to increase their use of natural refrigerants, especially CO2, in new systems.

"Several national chain food retailers have committed to CO2 transcritical architecture as their standard for new refrigeration systems nationwide, and based on data from our retailer members, we expect that trend to continue to grow," Wright said.

ALDI, a major U.S. supermarket chain, has committed to transitioning to natural refrigerants at all its 2,300-plus store locations by the end of 2035.

"Environmentally friendly refrigeration systems help keep our products fresh while limiting our impact on the planet," ALDI CEO Jason Hart wrote in a letter. "We already use environmentally friendly refrigerants in more than 600 stores, which has helped ALDI save nearly 60% of potential carbon emissions each year and earn recognition from the EPA GreenChill program for five consecutive years."

Coffin, who previously served as the director of sustainability and facilities at Whole Foods, said Whole Foods launched a completely synthetic refrigerant-free store in the U.S. in 2013. "For everything with a drop of refrigerants, we found an alternative more than a decade ago," he said. "We proved it could be done, and if it was possible then, it is more than possible now."

In recent years, many grocers have retrofitted from high GWP HFCs, such as R-404a and R-507a, to mid-range GWP refrigerants like R-448a and R-449a. "However, the combination of the state refrigerant ban under SB 1206 and the AIM Act Subsection H proposed rulemaking has many searching for more future-proof alternatives like natural refrigerants," Wright said.

NASRC's recent retailer survey forecasts over 300% growth in CO2 systems in new and existing facilities. "Given the large impact of refrigerants on Scope 1 emissions, food retailers cannot meet climate targets without addressing refrigerants."

Surprisingly, Wright said, there is still a large volume of industrial and cold storage systems in California using R-22 that will need to be addressed given price increases and limited availability.

Peter Thomas, president of Resource Compliance Inc., said he hasn't seen significant growth in the number of companies in California retrofitting systems or decommissioning older equipment and installing new.

"It is happening but there are still a lot of synthetic refrigerants being used," Thomas said, adding that he is concerned some end users in California aren't as focused on upcoming requirements as they should be. "They're just plugging along and not paying attention and it is all going to come to a head. They will be forced to make a decision, and it could be an expensive one."

Thomas added that end users need to give themselves enough time to source, install and train employees on new equipment.

When selecting new refrigeration equipment, Wright said companies should consider the business risks associated with HFCs. "What are the annual costs of refrigerant leaks as prices increase? What are the costs associated with refrigerant reclaim programs? What are the risks of lagging behind the market as competitors move to climate-friendly refrigerants? Natural refrigerants are the only future-proof alternative that can effectively address these risks," she said.

CHALLENGES REMAIN

Even with regulatory requirements and corporate sustainability goals driving the adoption of natural refrigerants, challenges remain. "Are there challenges to adoption and transition? Yes, but those challenges are no more complicated than maintaining the status quo," Coffin said.

The lack of available service technicians is an ongoing issue the refrigeration industry faces. "That is not specific to this transition. It is overall," he said. "Do we need to uptrain technicians? Absolutely."

In fact, Coffin said natural refrigerant systems could attract new talent to the service industry. "The advanced systems are more sexy than the old systems," he explained. "If you look at CO2, you're electrifying and digitizing a lot of the components. It is more appealing to the next generation," he said.

Looking Ahead

The first final rule of the AIM Act, which focuses on the phasedown of production and consumption, took effect on Jan. 1, requiring a 40% reduction in supply. "We know that in Europe, dramatic price spikes for HFC refrigerants began around this threshold, so we are expecting to see a similar impact in the U.S.," Wright said.

Under the AIM Act, the EPA is authorized to phasedown production and consumption of HFCs in the U.S. by 85% by 2036. The AIM Act's second rule, which focuses on technology transitions, puts GWP limits on specific refrigerant applications. "We're looking at 150 GWP for commercial refrigeration, for example, by Jan. 1, 2027, and then there is a whole list of applications in terms of their dates and when they transition to the GWP thresholds that are going into place," Coffin said.

Between 2025 and 2028, there will be restrictions on the sale of high GWP applications ranging from AC to commercial and industrial refrigeration.

Wright said she expects the final subsection h rule under the AIM Act, which will have significant implications on refrigerant management and reclaim, to be released this year.

Additionally, Coffin said those in the industry should keep an eye on regulations related to poly- and perfluoroalkyl substances, known as PFAS. The European Union's Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) proposal related to PFAS will be finalized in 2025.

"They may ban 10,000 chemicals that have PFAS. We are already seeing states talking about how they'd regulate PFAS," Coffin said. "That would also directly impact refrigerants, including the synthetic alternatives coming to the table as approximately 95% of them would be classified as PFAS."

Mergers and Acquisitions in the Refrigeration Industry Continue

The refrigeration industry has experienced several notable mergers and acquisitions, addressing the increasing need for ultra-low global warming potential refrigerant technologies and solutions.

"It's an exciting time in our industry as we continuously seek new opportunities to accelerate the deployment and adoption of safe and sustainable solutions and services," said Claude Allain, president, Johnson Controls HVAC/R and data centers.

Johnson Controls announced the acquisition of M&M Carnot, a provider of natural refrigeration solutions, in 2023. Allain said the acquisition would allow the company to better serve its growing customer base.

M&M Carnot designs and manufactures industrial refrigeration equipment and controls that use carbon dioxide. In a statement, David Sholtis, CEO of M&M Carnot, said joining Johnson Controls would allow the company to accelerate its work providing sustainable, natural refrigeration solutions.

"The support and resources of Johnson Controls will allow us to scale the business faster by bringing our innovative, environmentally friendly refrigeration and cooling technologies to a growing market in search of energy-efficient, green technology," Sholtis said. "We believe that together, we'll bring exciting new opportunities for our customers and employees alike."

M&M Carnot is one of North America's largest providers of transcritical CO2 solutions, including heat pumps and tailored solutions for data centers, positioning Johnson Controls to capture growing demand for the technology, the company said. Their combined engineering expertise and ultra-low-GWP technologies will also help Johnson Controls advance its commitment to cut customer emissions and support customers on their net-zero journey.

Other notable acquisitions in the refrigeration space include Danfoss's acquisition of BOCK GmbH, a provider of CO2 and low-GWP compressors utilized in cooling and heating applications.

"When there's more than one road to decarbonization, there's no such thing as too many solutions," said Kristian Strand, president of Danfoss Commercial Compressors, when announcing that the acquisition had been completed. "By adding BOCK's world-leading technology to Danfoss' extensive portfolio of compressors, valves, controls, heat exchangers and sensors, we are simply consolidating our position as the leading provider of greener cooling and heating solutions."

Evapco also expanded its offerings through the acquisition of Systèmes LMP to form the subsidiary Evapco Systems LMP, the company said. The new subsidiary combines Evapco's expertise in ammonia refrigeration with LMP's expertise in transcritical CO2 refrigeration.

"Evapco is now uniquely qualified to be 'The Natural Leader' of environmentally friendly, natural refrigeration-based products and systems," the company wrote on its website. "Evapco LMP, whose core business is the design and manufacture of transcritical CO2 systems, allows us to expand our full spectrum of natural refrigerant-based solutions and expand our low-charge, packaged refrigeration offerings to include not only ammonia-based Evapcold products but now CO2-based Evapco LMP products."

EPA Publishes Final Technology Transitions Rule to Phase Down HFCs

iiar government RELATIONS

BY LOWELL RANDEL, IIAR GOVERNMENT RELATIONS DIRECTOR

In October 2023, Environmental Protection Agency (EPA) Administrator Michael Regan signed the Final Rule Technology Transitions authorized under the American Innovation and Manufacturing Act designed to phase down hydrofluorocarbon (HFC) use. The AIM Act authorizes EPA to address HFCs in three main ways: (1) phasing down their production and consumption, (2) promulgating specific regulations for purposes of maximizing reclamation and minimizing releases of HFCs from equipment and ensuring the safety of technicians and consumers, and (3) facilitating the transition to next-generation technologies through sector-based restrictions.

The AIM Act included a process by which interested stakeholders could petition the EPA to establish sector-specific policies regarding the phasedown of HFCs. IIAR submitted a petition to the EPA recommending phasedown policies related to the refrigeration sector. IIAR's petition and petitions from several other groups were granted by the EPA in October 2021, triggering the EPA to initiate a rulemaking process. The Final Technology Transitions Rule addresses IIAR's petition and is largely consistent with the policies recommended by IIAR. The Final Technology Transitions Rule restricts higher-GWP HFCs in new aerosol, foam, refrigeration, air conditioning, and heat pump (RACHP) products and equipment. EPA has listed entities potentially impacted by the rule

In a few subsectors, such as some transportation applications, EPA has listed the specific HFCs or HFC blends that are restricted. Restrictions begin for many categories on January 1, 2025, with the latest restrictions going into place on January 1, 2028:

Sector	Systems	Global Warming Potential Limit	Installation & Manufacture and Import Compliance Date
Industrial process refrigeration (not using chillers)	With 200 or more lb refrigerant charge excluding high-temperature side of cascade system and temperature of the refrigerant entering the evaporator above -30°C (-22 °F)	150	January 1, 2026
	With less than 200 lb refrigerant charge and temperature of the refrigerant entering the evaporator above -30°C (-22 °F)	300	January 1, 2026
	The high-temperature side of cascade systems and temperature of the refrigerant entering the evaporator above -30°C (-22 °F)	300	January 1, 2026
	Temperature of the refrigerant entering the evaporator from -50°C (-58 °F) to -30 °C (-22 °F)	700	January 1, 2028
	Temperature of the refrigerant entering the evaporator below -50°C (-58 °F)	Not covered	Not covered

Sector	Systems	Global Warming Potential Limit	Installation & Manufacture and Import Compliance Date
Chillers	Industrial process refrigeration with exiting fluid below -50 °C (-58 °F)	Not covered	Not covered
	Industrial process refrigeration with exiting fluid from -50 °C (-58 °F) to -30 °C (-22 °F)	700	January 1, 2028
	Industrial process refrigeration with exiting fluid above -30 °C (-22 °F)	700	January 1, 2026
	Comfort cooling	700	January 1, 2025
	Ice rinks	700	January 1, 2025
Cold Storage Warehouses	With 200 or more lb refrigerant charge, excluding the high-temperature side of cascade system	150	January 1, 2026
	With less than 200 lb refrigerant charge	300	January 1, 2026
	The high-temperature side of cascade system	300	January 1, 2026

to include companies that manufacture, import, export, package, sell or otherwise distribute products that use or are intended to use HFCs, such as refrigeration and air-conditioning systems, heat pumps, foams, and aerosols.

The rule provides three mechanisms to restrict HFC use:

- Prohibiting the manufacture and import of products that use higher-GWP HFCs
- Prohibiting the sale, distribution, and export of those products three years after the manufacture and import restriction
- Prohibiting the installation of new RACHP systems that use higher-GWP HFCs.

In most subsectors, EPA has set a maximum GWP limit on HFCs or HFC blends that can be used.

It is important to note that this rule does not restrict the continued use of any existing products or RACHP systems. EPA has stated that allowing existing systems to continue to operate to the end of their useful life is important to ensure a smooth transition in the phasedown of HFCs. The rule clarifies that a product or system may be serviced and repaired throughout its useful life; this includes replacing components as needed. Components needed to repair existing RACHP equipment may continue to be manufactured, imported, sold, distributed, or exported.

Continued implementation of the AIM Act should provide additional opportunities to expand the usage of natural refrigerants. IIAR members are encouraged to familiarize themselves with the rule and EPA's other policies related to HFCs.

In the rule, EPA defines the distinction between maintenance of a system and installation of a new system. Specifically, the following actions, upon charging the system to full charge, are considered a new installation of a RACHP system and thus subject to the relevant HFC use restrictions:

- Assembling a system for the first time from used or new components
- Increasing the cooling capacity, in BTU per hour, of an existing system
- Replacing 75 percent or more of evaporators (by number) and 100 percent of the compressor racks, condensers, and connected evaporator loads of an existing system.

Continued implementation of the AIM Act should provide additional opportunities to expand the usage of natural refrigerants. IIAR members are encouraged to familiarize themselves with the rule and EPA's other policies related to HFCs. Further information on the Technology Transitions rule and the AIM Act can be found on the EPA website at: https://www.epa.gov/climate-hfcs-reduction.

iiar Standards UPDATE

BY TONY LUNDELL, CIRO, PMP, IIAR SENIOR DIRECTOR OF STANDARDS AND SAFETY

Ammonia (IIAR Suite of Standards)

IIAR 1: **ANSI/IIAR 1-2022 *Standard for Definitions and Terminology Used in IIAR Standards*** is presently in effect. It will be opened up for review starting in mid-2026 for its next revision with a targeted completion with ANSI approval in 2027. Rich Merrill serves as the IIAR 1 subcommittee chair and Tony Lundell, senior director of standards and safety at IIAR, is the IIAR staff facilitator. AN IIAR 1 future revision considerations (FRC) list has captured suggestions and considerations for its next revision.

IIAR 2: **ANSI/IIAR 2-2021 *Standard for Design of Safe Closed-Circuit Ammonia Refrigeration Systems*** is presently in effect. It will be opened up for review in mid-2024 for its next revision with a targeted completion with ANSI approval in 2026. Mark Bazis Jr. is the IIAR 2 subcommittee chair and Eric Smith, vice president and technical director at IIAR, and Lundell are the IIAR staff facilitators. An IIAR 2 FRC list has captured suggestions and considerations for its next revision.

IIAR 3: **ANSI/IIAR 3-2022 *Ammonia Refrigeration Valves*** is presently in effect. It will be opened up for review starting in mid-2026 for its next revision with a targeted completion with ANSI approval in 2027. Michael Trumbower is presently the IIAR 3 subcommittee chair and Lundell is the IIAR staff facilitator. This standard provides minimum "performance criteria" requirements for ammonia refrigeration valves and strainers used in closed-circuit ammonia refrigeration systems. AN IIAR 3 FRC list has captured suggestions and considerations for its next revision.

IIAR 4: **ANSI/IIAR 4-2020 *Standard for the Installation of Closed Circuit Ammonia Refrigeration Systems*** is presently in effect. It will be opened up for review starting in mid-2024 for its next revision with a targeted completion with ANSI approval in 2025. Don Faust, chair of the IIAR standards committee, is the IIAR 4 subcommittee chair. Lundell is the IIAR staff facilitator. AN IIAR 4 FRC list has captured suggestions and considerations for its next revision.

IIAR 5: **ANSI/IIAR 5-2019 *Standard for the Startup of Closed-Circuit Ammonia Refrigeration Systems*** is presently under revision. The IIAR 5 Subcommittee has been reviewing pre-public review comments and questions that were received. The IIAR 5 Public Review #1 Draft is targeted to be shared with the IIAR Standards Committee and the IIAR Board of Directors for their review in preparation for a vote during the IIAR 2024 annual conference in Orlando, Florida. The votes will be for approving the updated IIAR 5 revision's content and for it to go out for its first public review. The IIAR 5 revision is targeted for completion with ANSI approval in 2024. Nick Nechay serves as the IIAR 5 subcommittee chair and Lundell is the IIAR staff facilitator. The revision is addressing the standard to harmonize items with IIAR 2, IIAR 4, IIAR 6 and IIAR 7.

IIAR 6: ANSI/IIAR 6-2019 *Standard for Inspection, Testing, and Maintenance of Closed-Circuit Ammonia Refrigeration Systems* is presently under revision. The IIAR 6 Subcommittee has been reviewing pre-public review comments and questions that were received. "Functional Testing" of equipment, components and/or devices to clarify expected results was included and an "out of service" section was added to sustain the minimum requirements of IIAR 6 while a closed-circuit ammonia refrigeration system is shut down for an off-season, such as down/off seasons for fruit and/or vegetable harvesting or for down/off seasons for fish catching (seafood). The IIAR 6 Public Review first draft is scheduled to be shared with the IIAR Standards Committee and the IIAR board to review in preparation for a vote during the IIAR 2024 annual conference to approve the revised content and send it out for its first public review. The IIAR 6 revision is targeted to complete ANSI approval this year. Jeff Sutton is the IIAR 6 subcommittee chair and Lundell is the IIAR staff facilitator. The revision is addressing the standard to harmonize items with IIAR 2, IIAR 4, IIAR 5 and IIAR 7.

IIAR 7: ANSI/IIAR 7-2019 *Standard for Developing Operating Procedures for Closed-Circuit Ammonia Refrigeration Systems* is presently under revision. The IIAR 7 Subcommittee has been reviewing pre-public review comments and questions that were received. Several discussions have occurred to address regulated (i.e., PSM/RMP systems, more extensive systems with 10,000 lbs. or more) and non-regulated (i.e., General Duty Clause, smaller systems with less than 10,000 lbs.) sized closed-circuit ammonia refrigeration systems and addressed normative material versus informative/explanatory material. The IIAR 7 public review first draft is targeted to be shared with the IIAR Standards Committee and board so they can vote during the IIAR 2024 annual conference or shortly after, to approve the revised content and send it out for its first public review. The IIAR 7 revision should complete ANSI approval this year. Lesley Schafer is the IIAR 7 subcommittee chair and Lundell is the IIAR staff facilitator. The revision is addressing the standard to harmonize items with IIAR 2, IIAR 5 and IIAR 6.

IIAR 8: ANSI/IIAR 8-2020 *Standard for Decommissioning of Closed-Circuit Ammonia Refrigeration Systems* is presently in effect. It will be opened up for review starting in mid-2024 for its next revision with a targeted completion with ANSI approval in 2025. Peter Jordan is the IIAR 8 subcommittee chair and Tony Lundell is the IIAR staff facilitator. AN IIAR 8 FRC list has captured suggestions and considerations for its next revision.

IIAR 9: ANSI/IIAR 9-2020 *Standard for Minimum System Safety Requirements for Existing Closed-Circuit Ammonia Refrigeration Systems* is presently under revision for the development of an addendum. IIAR 9-2020 Addendum A (202x) was developed to address a scope change and an interpretation, provide a clear compliance deadline, address some simple edits and provide a flow chart. The first public review of the addendum received 16 comments and questions, which the IIAR 9 Subcommittee has been reviewing for consideration and developing responses. Eric Johnston is the IIAR 9 subcommittee chair and Lundell is the IIAR staff facilitator. The addendum is targeted to be completed with ANSI approval this year.

Carbon Dioxide (IIAR Suite of Standards)

IIAR CO2: ANSI/IIAR CO2-2021 *Safety Standard for Closed-Circuit Carbon Dioxide Refrigeration Systems* is presently in effect. An addendum has recently been considered. John Collins is the IIAR CO2 subcommittee chair and Lundell is the IIAR staff facilitator. Where or if an addendum is pursued, the IIAR CO2 Subcommittee will reconvene to finalize the considered addendum details and it is targeted to be completed with ANSI approval this year.

Hydrocarbons (IIAR Suite of Standards)

IIAR HC: IIAR HC-202x *Safety Standard for Closed-Circuit Refrigeration Systems Utilizing Hydrocarbon Refrigerants* is a standard presently in development. This standard pertains to utilizing "natural" hydrocarbon refrigerants with zero ozone-depleting potential and very low global warming potential. The committee is currently reviewing and developing responses to one-hundred-sixty-one (161) comments received during the first (1st) public review. Joseph Pillis is the IIAR HC subcommittee chair and Lundell is the IIAR staff facilitator. The IIAR HC's second public review, resulting from the first public review substantive and informative changes, should be ready in early-mid 2024.

Lundell said IIAR is strengthened by the members who volunteer their time for the standard committee, as voting and corresponding members, and the members who volunteer their time for the 11 standard subcommittees which play an essential role in the association's work. "They are volunteers, and they are helping us as a natural refrigeration industry develop 'recognized and generally accepted good engineering practices' as consensus standards and the developed of other RAGAGEP guidelines that are what we want for our destiny," he said.

IIAR Annual Conference to Provide Technical Knowledge, Industry Insight to Members

IIAR's 2024 annual Natural Refrigeration Conference & Expo in Orlando, Florida, March 24-27 will provide technical knowledge, networking and industry-sponsored events for those involved in the natural refrigerant industry. There will be numerous educational opportunities throughout the conference, and attendees can earn professional development hours.

"We have a fantastic program this year, with several new networking opportunities, a Student Day on Wednesday, a super fun Monday night event, more Product Showcase Opportunities, which were previously known as 'Technomercials,' a heavy equipment exhibit, and a wonderful tech program that includes workshops, in-depth technical presentations and several industry panels," said Yesenia Rector, IIAR's meetings and international program director.

FUN IN THE SUN

The event officially kicks off on Sunday, which is dedicated to fun and making new connections.

The Natural Refrigeration Foundation's first Fun Day will take place on Sunday, the first day of the 2024 IIAR Conference. The goal is to raise awareness and donations for the NRF and its mission. The Fun Day will feature the Annual NRF Golf Tournament and the second annual NRF Pickleball and Cornhole tournaments.

"We will host these NRF tournaments in conjunction with the IIAR Conference & Heavy Equipment Expo in support of the Natural Refrigeration Foundation and the Founders' Scholarship Fund," Rector said.

Following the activities, the NRF Tournaments Awards Ceremony and VIP Reception will celebrate the day's winners and thank Foundation supporters.

The annual meeting is always full of networking events for attendees to connect with each other. The Diversity in Natural Refrigeration Reception on Sunday evening is designed to help foster an inclusive environment that welcomes individuals from all walks of life and unlocks a wealth of unique perspectives, experiences and ideas that drive innovation and propel the refrigerant industry forward.

Sunday also features the First Timers Reception, Chairman's Reception and Scholarship Students Dinner.

INDUSTRY EDUCATION

IIAR has created numerous in-depth learning opportunities. The conference's technical program offers professional development hours to all attendees.

The feature panel, History of Ammonia and IIAR: Together for Over 50 Years, will delve into the evolution of refrigeration and the history of IIAR.

"Andy Pearson from Star Refrigeration who has written an excellent historical perspective on refrigeration, particularly ammonia refrigeration dating back to its invention in the 19th Century, will present his work," said Eric Smith, technical director for IIAR. "Then we have the president emeritus of IIAR, Kent Anderson, who has teamed with Vern Karman, a long-time member and a second-generation IIAR officer who was instrumental and fundamental in developing some of the first IIAR publications."

The session will offer a trip down memory lane, touching on some of the key members and their accomplishments. "Hank Bonar, an industry elder who is still practicing, will share some IIAR history but will focus primarily on the major technological developments he has witnessed along the way in his career and the effects of how these technologies have made our industry better, safer and more efficient," Smith said.

Another panel will bring together a group of regulatory compliance specialists to provide their perspectives on compliance. "Individuals in this group represent different companies and approaches to regulatory compliance. We're getting them all together in one room so the audience can get their compliance education at the same time in the same place," Smith said.

The closing forum will provide an update on the AIM Act and the State of the Industry. "We have many highly knowledgeable professionals in this panel that should not be missed," Rector said.

Panelists will cover the implications of the global drawdown of HFC refrigerants, the impact of the U.S. AIM Act on domestic, industrial and commercial end users, and the future of natural refrigerant use in a broader market.

In addition to the panels, industry experts will present a dozen technical papers that cover critical industry issues, including safety, efficiency and new technology.

TRAINING AND CERTIFICATION

IIAR will host RETA's CRST Certification classes on Friday, Saturday and Sunday, culminating with the RETA Certifications Testing Opportunity on Monday.

STUDENT DAY

The 2024 IIAR Conference will also have its inaugural "Student Day" in Orlando. The Student Day on Wednesday gives university and technical college students an opportunity to learn more about the industry and meet with exhibitors individually to learn more about careers. Students are always welcome, but having a dedicated day where the students can gain the perspective of industry leaders, see and discuss equipment, and connect with employers benefits employers, students and the industry as a whole.

"The whole idea is we attract younger people into our industry, so it continues to grow," Smith said. "We recognize that our industry needs more good talent, and we hope that the Student Day will help to increase young people's awareness about our industry and its importance."

Recipients of the NRF Scholarships are invited to attend the entire event and will have the opportunity to meet with the IIAR executive team, the NRF Board and Trustees, and exhibitor hosts who will guide them through the showroom floor and introduce them to industry partners and veterans.

COMMITTEE MEETINGS

Ahead of the official meeting, committee meetings, which are where a lot of the association's in-depth work gets done, will take place on Friday and Saturday. There will also be a special IIAR Board and Committee Members VIP Dinner on Saturday, by invitation only, designed to thank committee chairs, members, board of directors and international partners who devote their time and effort to support the IIAR mission.

"I am excited about the Saturday night VIP event where we have, for the first time, invited not just the IIAR board and IIAR committee chairs, but we have invited all committee members, all VIPs, such as those from international and domestic allied organizations," said Gary Schrift, IIAR's president.

View the full schedule and additional details on the conference at www.iiar.org.


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Technical Papers Provide In-Depth Thought Leadership at the IIAR Conference

During the annual IIAR Industrial Refrigeration Conference & Exhibition, industry experts will present technical papers for the IIAR Technical Program. This year's papers will address several key categories, including heat exchangers, cold storage, ammonia charge, CO2 optimization and more. There is also a series of workshops and panels that will discuss various other topics.

Eric Smith, IIAR's vice president and technical director, said the papers provide breadth, depth, and applicability that isn't generally combined at other refrigeration-specific conferences. Several papers stand out within this year's lineup.

"Application and Considerations for Internal Relief in Industrial Refrigeration Systems" by Todd Jekel and Douglas Reindl, Industrial Refrigeration Consortium, addresses the appropriate use of vapor and liquid pressure relief devices.

"Liquid relief devices especially have been observed to sometimes be inappropriately installed," Smith said. "The paper hopes to clear up when liquid relief should be used and how to provide appropriate calculations when it is used."

The paper will provide much-needed guidance to the industry on the appropriate applications of relief valves and guide the industry on the best devices for overpressure correction. "The IIAR Standards Committee will likely use it to refine the IIAR-2 Standard," Smith added.

The paper "Controlling the Circulation Rate in Ammonia Refrigeration Systems" by Morten Juel Skovrup, Niels Vestergaard and Roozbeh Izadi-Zamanabadi with Danfoss A/S details an innovative technique to lower charge by sensing the quality of the leaving refrigerant.

"Our paper will introduce a new solution for controlling evaporators in ammonia systems. Controlling evaporators correctly is crucial for enabling low ammonia charge," Skovrup said, adding that

The papers provide breadth, depth, and applicability that isn't generally combined at other refrigeration-specific conferences. Several papers stand out within this year's lineup.

presenters will share results from testing the control solution in lab and field tests.

The new control solution ensures the control of the injection of ammonia into evaporators but does it in a way so that the efficiency is not compromised. “The control solution is plug and play, and can in many cases be used for retrofit,” Skovrup explained.

Lowering the ammonia charge can reduce risk, but it needs to be done to maintain system efficiency. “Furthermore, lowering the ammonia charge - but especially controlling it - can increase the efficiency of the entire system by minimizing pressure drops, especially in suction lines,” Skovrup said.

“Application of Rotary Pressure Exchanger in CO2 Refrigeration Systems” by Neelesh Sarawate Azam Thatte and Karina Lao; Energy Recovery, highlights application of a rotary gas pressure exchangerto increase efficiency of transcritical CO2 refrigeration systems.

According to the paper, CO2 Refrigeration systems with rotary gas pressure exchangers have been installed at multiple supermarket locations in Europe and North America. These devices have operated over several months at these locations and have demonstrated +30% energy savings while maintaining smooth control of gas cooler pressure and handling a wide range of loads.

“It appears to be an innovative way to make CO2 systems that operate transcritcally more efficient by reusing the energy that would normally be lost in the expansion of the supercritical gas,” Smith said. “This is important because the use of CO2 systems is anticipated to become more and more prominent in high ambient temperature conditions. It is crucial to manage efficiency as best you can.”

The availability of a new and innovative technique to increase transcritical operating efficiency could potentially help generate more prolific use of CO2 systems in high ambient conditions.

Technical **PAPERS** AT A GLANCE

Each technical paper presented at IIAR’s annual conference contains specific, actionable information about the refrigeration industry.

2024 IIAR Tech Papers:

Reliable, Efficient and Safe Heat Exchangers for High Pressure Applications, Grecia Ayala and Zachary Ellis, Alfa Laval Inc.

Decarbonization with Falling Film Chiller and Heat Pump Integration: An Energy-efficient Method for Producing Cold and Hot Water in a Dairy Plant; José Augusto Castro Chagas and Daniel Camps Puchol; Castro Chagas Consulting

Carrots to Sticks—Carbon Tracking for Cold Storage; James Majsak; CrossnoKaye

Implications of HAZWOPER Emergency Response Regulations on Contractors; Jeff Pace; Industrial Refrigeration Pros

Application and Considerations for Internal Relief in Industrial Refrigeration Systems; Todd Jekel and Douglas Reindl; Industrial Refrigeration Consortium

CO2 System Add-Ons: Calculations and Field Measurements; Giacomo Pisano; Dorin, USA

Application of Rotary Pressure Exchanger in CO2 Refrigeration Systems; Neelesh Sarawate and Azam Thatte; Energy Recovery

Intelligent CO2 Compressors and Ejectors for Enhanced System Efficiency and Reliability in Industrial Applications; Alessandro Silva; BITZER U.S.

Controlling the Circulation Rate in Ammonia Refrigeration Systems; Morten Juel Skovrup, Niels Vestergaard, Roozbeh Izadi-Zamanabadi; Danfoss A/S

Potential Energy Savings in Ammonia Systems through Use of Low-Stage De-superheating; Hannes Steyn; GEA Africa (Pty) Ltd.

Five Best Practices for Energy Baselining; Charles Tuck; Ndustrial.io

Comparison of 20+ years of NDT Samples with Documented Field Observations: A Case Study; Suzy Vohsen; Gamma Graphic Services

Training on Ammonia Systems Keeps Employees and Facilities Safe

Training at ammonia refrigeration facilities is critical to ensure safety and comply with regulatory requirements. Nearly everyone who works at a location with ammonia onsite needs training, even if they don't work on the systems directly.

"Training is everything. Without a great training program, you're asking for trouble," said Aaron Christopherson, EHS manager at E. & J. Gallo Winery.

Christopherson added that in addition to improving safety, providing training can increase retention because it creates a career path for employees and an opportunity to advance. "As they get more education and certifications, they get higher pay as well," Christopherson said. "Somebody said, 'What if we train people and they leave?' There is a risk with that, but what if we don't train them and they stay?"

The level of training employees need varies based on their work, and there are several resources to ensure all workers get the training they need, including bringing training providers onsite, sending employees to classes, developing in-house programs or tapping into online programs.

ESTABLISHING GOALS

Training aims to improve an employee's capability, capacity, productivity, safety and performance, explained Jeremy Williams, owner of Ammonia Refrigeration Training Solutions (ARTS), which provides industrial refrigeration training throughout the United States.

To help ensure success, goals and objectives should be tailored to the specific training modules or segments. "Employers should describe the important actions and conditions under which the employee will demonstrate competence or knowledge as well as what is acceptable performance," Williams said, adding that learning goals and objectives should be measurable before the training begins.

CREATING AWARENESS

Anybody who steps foot in a facility with ammonia should receive awareness training. This includes new hires, all employees and all visitors. "It covers the general characteristics of ammonia, including the hazards, the location(s) where ammonia is handled at that facility, and what to do if there is an emergency, for example, if you smell ammonia," said Peter Jordan, principal engineer at MBD Risk Management Services.

Because the awareness training is general, Peter Thomas, president of Resource Compliance Inc., said it can be provided onsite or through an online course.

DIGGING DEEPER

Employees who operate or maintain a refrigeration system need more advanced training on system operating and maintenance procedures, such as how to stop and start equipment. Employees need to know how to do their jobs safely, and the amount of training they require can vary depending on their tasks. “There are things more senior operators need that junior operators don’t and that can change over time,” said Stephanie Smith, principal engineer, Risk Management Professionals.

Management decides who receives more advanced training, but Williams said it can be useful for any worker that could affect the refrigeration system. “This can range from roundsman, operators, mechanics, technicians, electricians, contractors, engineers and various management roles,” he said.

E. & J. Gallo Winery has two primary teams working with ammonia—chiller operators who run and monitor chillers when they’re running and refrigeration mechanics who are full operators. Anybody who will be on or near ammonia assets receives the Refrigerating Engineers & Technicians Association’s (RETA’s) Industrial Refrigeration I training. “That is ammonia theory. Once they’ve completed that course successfully, they can start the on-the-job training,” Christopherson said.

The on-the-job training covers E.& J. Gallo Winery’s equipment and how to apply ammonia to the company’s processes. “We have an in-house program that talks about how we do ammonia,” Christopherson said. “Then you can go out and work with your trainer to learn more.” Employees have a list of things they have to check off before they work on their own.

Mechanics go through the same process but already have a maintenance background. “They know how to work on pumps, motors and seals. They need the Book I training. Once they’ve had that, they can start going out with somebody and get into the refrigeration mechanic training program,” Christopherson said.

Operators and mechanics eventually move on to RETA’s Industrial Refrigeration II training. Operators and backup operators also complete Certified Assistant Refrigeration Operator training, and mechanics can compete in Certified Industrial Refrigeration Operator training. “The bottom line is if you touch ammonia once a year or every single day, you carry the same risk. There is no difference,” Christopherson said.

Training requirements apply to contractors as well. If contractors perform the work of an operator mechanic, they need to be trained like an operator mechanic. Training should include information on what they can access and safety practices, including lock-out/tag-out procedures. “Either you give it to them, or their company gives it to them,” Jordan said.

GETTING SITE SPECIFIC

Every ammonia refrigeration system is a little different, and some of the most essential training is facility-specific training that highlights the company’s procedures and processes. Anyone working with equipment needs training on site-specific operating procedures, such as start-up, shut-down and maintenance.

“All operators and all mechanics don’t have to be trained on all procedures, but they need to be trained on any tasks they would perform,” Jordan said.

PREPARING FOR EMERGENCIES

Emergency response planning needs to be done to comply with the Hazardous Waste Operations & Emergency Response (HAZWOPER) standard, which Jordan said contains different requirements than operator training. Facilities must decide whether to train first responders at the operations and technician levels.

“First responder operations level are individuals who respond defensively to an ammonia release,” Jordan explained. “They go to the system where there could be a release and verify there has been a release but don’t expose themselves to a level of danger. They contain it from a safe distance.”

It requires eight hours of initial training and then refresher training once a year. “It is unspecified how long the refresher has to be,” Jordan said.

HAZWOPER technician-level training allows responders to go in with personal protective equipment. “The training requirements are 24 hours of initial training and eight hours of refresher training after that,” Jordan explained.

Facilities must also train incident commanders, who receive additional training and have the ability to devise and implement company, local and state emergency response procedures and plans.

COMPLYING WITH REGULATORY REQUIREMENTS

Regulatory requirements dictate some training needs. “The tricky thing with regulations is they don’t tell you what you need. They just tell you that you have to have it,” Smith said. “It is an open book because every facility is different, but there are basics.”

Jordan said OSHA’s PSM Standard and EPA’s RMP regulation have specific requirements for operator training. To comply with PSM/RMP requirements, operator training must be conducted once every three years but can be done more frequently. The PSM/RMP regulations require facilities to ask employees how often they want training repeated. “If most say every three years, that is okay. If the majority say they want it more often, for example, once a year, then annual training should be conducted.”

Most ammonia facilities with under 10,000 pounds of refrigerant are not subject to PSM/RPM, you’re under general duty clause, and we have an Ammonia Refrigeration Management program,” Jordan said. Under ARM, training doesn’t have specific time requirements.

Seasonal facilities that shut down or are drastically reduced during the off-season should consider holding refresher training for all employees when the season ramps up. “I work with agricultural clients where some of the labor force is seasonal, and there is a lot of turnover from one year to another. It almost makes sense to do it annually,” Thomas said.

MEETING EMPLOYEES NEEDS

Williams said everyone learns differently, and an effective training program will allow employees to fully participate in the training process and practice their skills or knowledge. "A properly conducted training program will ensure comprehension and understanding. It is not sufficient to either just read material to workers or simply hand them material to read," he said.

Hands-on training where employees can use their senses beyond listening can enhance learning. "Hands-on can both be in the classroom with cut-aways and in the field," Williams said.

Differing teaching methods can help engage employees with different learning styles. "It is important that people are sensitive to that and avoid death by PowerPoint or doing video series after video series," Thomas said. "The online videos have improved efficiency, but the downside is they can become boring, routine, or people are unengaged. The name of the game is engagement."

Smith noted that some people are visual learners while others are verbal learners. "A presentation can be helpful because you're combining verbal with visual," she said, adding that since comprehension is critical, facilities may need to offer training in multiple languages.

If someone is working around a system and doesn't understand the training, the supervisor must make time to re-do it, re-verify it, or figure out where the gaps are. "Taking the time to do that is better than having an incident," Smith said, adding that after an incident or near miss, part of the investigation should focus on procedures and whether they're adequate. "That is an opportunity to look at training."

The PSM/RMP regulations require facilities to verify that operators understood the training, which can be done through testing. "It could be written testing, which is what many people do because it is easy and defendable, oral or demonstration. You have to document how you tested and how they scored," Jordan said.

INSOURCING VS. OUTSOURCING

There are several training resources available to facilities. "There are some trainings that are perfectly fine to outsource. Anything facility-specific—operating procedures and emergency drills—should be done by internal staff," Smith said, adding that the exception would be if the contractor has extensive knowledge of the system or helped write the emergency plan.

Thomas said there are several good hands-on training schools. "You could invest some money, get on a plane, get a hotel and take a week-long course. Those can be helpful, but the downside is they are expensive, and you must travel unless you're near one," he explained.

Bringing trainers onsite is more cost-effective when multiple employees need training. "If you're considering sending five people away to become trained, it might be more effective to bring that training to you. Then you can even get hands-on training for your system," Thomas said.

ARTS has both online options to develop employees' skills and knowledge in specific useful competencies, and its most popular courses are ammonia refrigeration safety, introduction to ammonia refrigeration, PSM/RMP, ammonia operator 1, and ammonia operator 2.

Christopherson takes a multi-pronged approach, tapping into outside training, industry experts, and the company's internal resources. EJ Gallo has an in-house training department that works with subject matter experts to create its onsite training. "You get everything on paper and train everybody to that standard. It comes with operating procedures, work instruction and job instruction."

The type of training locations used often varies in size and breadth. "The larger, more experienced the facility, the more they can take on internally. Smaller operations rely on outside trainers more," Jordan said.

No matter what, facilities should be wary of training where the majority of time isn't spent on the actual training. "That can happen at trade shows or sometimes safety days. I love both of those, but an employer might think they're sending an employee to a week-long trade show for training, but they need to make sure they're going to the sessions rather than taking a day off of work," Thomas said. "That can be validated by making them bring back documentation that they did attend the session."

FINDING TRAINERS

Locations seeking training resources should get recommendations from someone they trust. "You want someone who specializes in refrigeration, but at some point, you have to bite the bullet and bring them in to try them out," Jordan said.

Williams said that just because someone is educated, credentialed or experienced doesn't mean the person is an effective trainer. Instructors must demonstrate competent instructional skills and knowledge of the applicable subject matter.

KEEPING TRACK

Training needs to be documented, and facilities are required to keep records. "If it wasn't documented, it did not happen," Thomas said.

Records should include the name of the training or the topic, the duration, the names of all the people who participated in the training, the trainer's name, and the means used to verify that the training was understood. Facilities could go further and have employees sign paperwork confirming they completed the training. "The law doesn't prescribe the employees have to sign it, but there is better credibility if that is the case," Thomas said.

Often, with training, people just miss it. "It has to be every three years, but some should be done more often, and that is when you start losing track of what is needed when," Smith said. "It has gotten better with databases and software to track training. It makes sure training is consistent."

Tracking training doesn't have to be complicated. "The most difficult part is making sure the deadlines are met for each person and keeping the records," Smith said.

LOOKING AHEAD

Training may also extend beyond ammonia as more and more natural refrigerants are adopted.

"CO2 and hydrocarbons aren't covered by PSM, but you could make the case that training needs are even greater because there are fewer trained people in the technologies, and the history and institutional knowledge isn't there," Thomas said. "I think there will be a huge opportunity to fill that void for other natural refrigerants."

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IIAR Marked Notable Accomplishments Throughout 2023

IIAR staff and IIAR's many volunteer committees were hard at work throughout 2023 and have strengthened the membership offerings, provided valuable education, and furthered the organization's mission through advocacy, work with regulatory agencies and new partnerships.

OFFICE IMPROVEMENTS

IIAR's staff and back-office systems keep the association running smoothly and ensure members get the support and resources they need. In 2023, IIAR added two new staff members—a membership coordinator and a conference/meetings expo coordinator. "We've doubled our bandwidth for member support," said Mike Chapman, director of business operations for IIAR. "The new membership coordinator is a direct member-facing position who helps with quick resolutions for our members."

The conference/meeting/expo coordinator assists with meeting and event planning for the Board of Directors and committees and supports many aspects of the annual conference and Expo through planning and coordination of logistics for the event, "The conference is a big event, and there are a lot of moving parts. We're now spreading that workload, managing tasks to make our overall operations more efficient and effective," Chapman said.

In addition, IIAR upgraded the association's management software, which is now in the cloud and has improved functionality and integrations of member resources. "We want to synergize and streamline as much as we can to improve our organizational capabilities and member offerings," Chapman said.

Throughout the year, staff created new job descriptions, detailed tasks and needs and outlined communications processes. "The goal is to make us more resilient and broaden the knowledge base, so everybody doesn't have to be a specialist," Our unique team has an amazing skill set. Still, as we cross-train, we build supporting resources for each other and the organization Chapman said, adding that staff spent time cleaning up email addresses, email groups and distribution lists to ensure proper distribution of IIAR information.

IIAR's publications have also been streamlined. Previously publications were done by multiple entities. As part of the shift, IIAR will do more demand-based printing, saving money and making purchasing materials more efficient.

ORGANIZATIONAL ENHANCEMENTS

IIAR completed several changes to help enhance the organization. These include a new diversity policy and a rebranding. As part of the rebranding, the International Institute of Ammonia Refrigeration became the International Institute of All-Natural Refrigeration.

This was also the first full year IIAR fully marketed the new name for NRF, Natural Refrigeration Foundation. As part of the transition, staff has created a brand standards manual with new logos, tagline, mission and vision. NRF also launched a Google Ads campaign and increased social media marketing on top platforms, including LinkedIn and Facebook.

The association also released a new IIAR video and a new NRF video and updated the websites for both organizations.

NEW MEMBER OUTREACH

Staff has embarked on several projects to attract new members and provide value to existing members. As part of this effort, staff plans to attend, exhibit and speak at other conferences and trade shows, such as ASHRAE/AHR, the Ice Rink Association and others. Attending these conferences will increase IIAR's exposure and provide valuable education about natural refrigerants.

IIAR's Condenser magazine has gone fully digital and will provide members and non-members access to future and past issues online. While PDF versions were available in the past, all articles will now be in the cloud, so readers can use their favorite search engine to look for and easily find topics important to the industry. Select Condenser articles will be translated into Spanish for IIAR's Spanish-speaking members and global partners.

IIAR has also launched a new website devoted to the AIM Act, AIMAct.org and added information about the AIM Act to a dedicated webpage on the IIAR website. IIAR is also near completion of the Refrigerant Evaluator Tool that will be added to the website.

IIAR launched a new chapter in Brazil, legalized with chapter officers and is moving forward with its alliances with the International Institute of Refrigeration in Paris and the North American Sustainable Refrigeration Council. Additionally, IIAR has become an official partner of UNEP's Cool Coalition Program (UNEP is the United Nations Environment Programme).

"By partnering with IIAR, we strengthen our commitment to sustainable cooling solutions and nature-based approaches. Together, we'll continue to advance the cause of responsible refrigeration practices and advocate for a greener future," the UNEP Coalition said in a statement.

MEMBERSHIP ENHANCEMENTS

Throughout 2023, IIAR staff fine-tuned the membership structure to create a more efficient renewal and notification process. Staff are also working to bolster membership and retention. When non-members contact IIAR with questions, for support or other information, the IIAR membership team makes contact and encourages them to consider membership. Staff also reaches out to exhibit space applicants to see if they want to become members.

If existing members don't renew, the membership team also follows up with them to learn why and see if there is anything they can do to provide additional support.

All IIAR members have access to IIAR Standards, and staff are continuing to educate members on this digital access and have created information on frequently asked questions to provide additional guidance.

The association has also created the Natural Refrigerant Directory, which is a new member benefit where group member companies can provide their contact information, which is then organized by company type, such as manufacturer, end-user, education, etc.

Anyone looking for natural refrigeration expertise can use the page as a resource.

ANNUAL CONFERENCE ENHANCEMENTS

The annual conference and exposition is a top priority for IIAR, and staff has taken steps to maximize the educational, networking and fundraising opportunities it creates. The association has implemented an online sales system for exhibit spaces and sponsorship sales for IIAR and NRF.

"This means that now, potential sponsors can select their desired sponsorship for IIAR and NRF and conveniently pay online," said Yesenia Rector, IIAR's meetings and international program director. "Also, exhibitors can pay their IIAR invoices for the conference online. These improvements have allowed our sponsors and exhibitors to experience the convenience and time savings of a streamlined process."

This year's exhibit hall sold out for the first time. IIAR continues to prioritize prior-year sponsors to select their exhibit space first, followed by prior-year exhibitors before opening exhibit sales to the public. "That said, though, we established an exhibitor ranking system where total prior year conference spend is used to prioritize exhibitors within those groups," Rector said. "This has enabled a more transparent and orderly process for exhibit space assignments."

NFR is also moving forward with its Fun Day at the IIAR conference and is holding the golf tournament as well as the second annual pickleball and cornhole tournaments. Proceeds support the foundation's mission.

The conference also features a Student Day on Wednesday morning, where college/technical school/university students can learn about the Natural Refrigeration Industry and meet with the companies exhibiting at the Expo. The Wednesday Student program introduces the natural refrigeration industry, including an overview of the world's regulatory landscape and the work IIAR has been doing to ensure sustainability for this industry by reducing global warming and ozone-depleting refrigerants.

This year, and going forward, IIAR will be honoring the work that the committee and the board of directors members have been doing to support its mission by holding a VIP Event dedicated to all these hard-working individuals.

MISSION ACHIEVEMENTS

Research, education, information sharing, and advocacy are critical parts of IIAR's work. Throughout 2023, IIAR focused on several research projects, including hydraulic shock and CO2 relief headers.

"The IIAR/NRF condensation-induced hydraulic shock research project is intended to further understand the phenomenon of high-pressure shock occurring when hot ammonia gas is rapidly introduced into piping or header sections containing cold liquid ammonia. There have been a few instances of catastrophic failures resulting from CIHS," said Eric Smith, technical director of IIAR.

The current project builds on several earlier studies that enabled the development of computational fluid dynamic modeling that predicts the circumstances and outcomes of CIHS. This project should help the industry "right-size" hot gas solenoid valves and piping such that when combined with other good design practices, CIHS would be virtually eliminated as a concern.

The use of CO2 as a refrigerant is becoming more widespread. While many technological advances have been made in the past decade, one aspect that is not fully understood is whether dry ice can form when high-pressure CO2 is released into a pressure relief header.

"Some people believe this would never happen, while others believe the opposite," Smith explained. "The CO2 relief piping research project aims to answer these questions, by studying the geometries, relief conditions, pressure losses, heat transfer, and energy transitions of CO2 as it passes through relief valves and is routed through relief headers."

On the advocacy front, IIAR influenced the EPA AIM Act's final ruling for the technology transition. "Congress charged the EPA via the AIM act to phase out high GWP refrigerants. When the EPA requested comments and proposals for the technology transition phase, IIAR submitted a petition to the EPA recommending GWP limits for various refrigeration applications related to commercial and industrial processes," Smith said.

The petition obviated that for most of these applications, a natural refrigerant solution was already available for either direct or indirect cooling processes. Thus there was no technological reason to permit high GWP limits in the most common applications. Subsequently, IIAR met a few times with EPA staff to explain the types of equipment and the codes and standards that were applicable for the various applications.

"While we cannot be certain that the petition had any bearing on the final rulemaking, at a minimum the IIAR made it clear that the natural refrigeration industry is ready, and has been preparing for years, to accelerate the transition to low GWP technologies," Smith said.

Among several advocacy efforts over the past year, IIAR engaged with a team of other associations to assemble a report to the New York State Department of Environmental Conservation to assist in their efforts to assess the viability of natural refrigerants. IIAR participated in a series of technical working group meetings with the overarching goal to collect impartial information on the barriers and opportunities for natural refrigerants to be used across the various end-use sectors while complying with state and federal regulations for greenhouse gas reduction, safety and energy efficiency.

The working group members represented a cross-section of people and organizations who directly work with natural refrigerants in the U.S. or have highlighted the need to address the barriers to their adoption.

The group consisted of climate science and policy experts, manufacturers and suppliers of equipment that uses natural refrigerants, design and engineering consultants, safety standards and building code experts, other non-profit policy advocacy organizations, representatives of end-users, as well as New York state and city officials. Hopefully, this effort will be a catalyst for New York to ease and accelerate the use of natural refrigerants throughout the state.

There were several standards development and updates in 2023. The IIAR hydrocarbon standard (IIAR HC) and IIAR 9 Addendum are through their first public review. IIAR 5, 6 and 7 ini-

tial revisions are nearly complete with the next steps being public reviews.

As part of the IIAR 6 revisions, the associations developed and included expected results for each functional testing requirement and added an out-of-service section, which focuses on systems shut down between seasonal harvests, such as produce or seafood.

"The key pertaining to IIAR 6 is that the ammonia refrigeration systems are required to have inspection, testing and maintenance tasks accomplished during the peak season and be addressed during the non-peak harvesting season to sustain mechanical integrity and be prepared to safely startup for the next season. While during the non-peak harvesting season, IIAR 6 addresses the inspections, tests and maintenance tasks for sustainability and readiness," said Tony Lundell, senior director of standards and safety for IIAR.

In addition to the regular work of standards development and revisions, ANSI conducted its scheduled audit of IIAR standards development practices. The audit revealed that IIAR's process was executed virtually without flaw. Another improvement is that the standards commenting tool has been revised to force commenters to provide more details, including the section referenced, how they want it to read, and provide a clear justification for the recommended change. The standards comment tool also has been arranged to have a DigiCert protection.

On the educational side, IIAR provided several educational sessions, including five at RETA Chapter virtual events, four live presentations at the Blue Ridge Chapter Expo, and eight live presentations at the 2023 RETA Conference. Presentations were also given to IIAR members either virtually or live.

As part of its educational offerings, IIAR presented webinars on both revised and new topics, addressing 29 CFR 1910.119 Process Safety Management (PSM) requirements, Safe Work Practices performed/required in the refrigeration industry, General Duty Clause (GDC) requirements and enforcement awareness, Progress in Natural Refrigerant Codes and Standards, and the IIAR Membership Program clarifying the member types, benefits, and costs.

Staff also gave international presentations in Brazil and Costa Rica, presented at the Process Heating and Cooling Show in Chicago, presented at the Ammonia Safety Day and delivered multiple IIAR presentations and discussions about "Enforcement Awareness! General Duty Clause Requirements" to ensure owners identify hazards using appropriate hazard assessment techniques no matter the size of the ammonia refrigeration system.

Other presentations and discussions included: "Progress in Natural Refrigeration Codes and Standards (NH3, CO2, HCs)" and a "Heat Stress Protection and Cold Stress Protection" IIAR Webinar. At GreenChill, IIAR delivered a presentation and answered questions for progress in natural refrigerants related to ammonia, carbon dioxide, and hydrocarbons.

Staff time was also devoted to technical support and advocacy. Projects included supporting Grifols Pharmaceutical company to address projects to meet ANSI/IIAR 6-2019 and supporting Novo Nordisk during weekly calls to address design questions and requirements for ANSI/IIAR 2-2021, as well as an introduction to ANSI/IIAR 6-2019.

The association challenged NIOSH, which was accepted to have the range of ammonia set at 16% to 25% instead of 15% to 28%. "The importance of the range being 16% to 25% correlates with the flammability range of anhydrous ammonia," Lundell said. "Mixtures below or higher than this flammability are not subject to ignition. New ammonia refrigeration systems must have ammonia detectors that activate at 25ppm, triggering ammonia audio and visual alarms."

A major ammonia refrigeration end-user submitted numerous questions to the IIAR staff about the minimum requirements for the design of safe closed-circuit ammonia refrigeration systems. Responses were developed for each of the questions received along with some examples as needed to provide clarification.

"The end-user mainly uses ammonia refrigeration for cold storage and shipping purposes. Their questions were driven by their desire to make all their facilities compliant. But because their core focus was storage, many of their questions were about design aspects for production and processing facilities," Smith said.

IIAR staff provided examples and explanations of standards requirements with which they were unfamiliar, permitting them to either include or exclude the requirements in evaluations of their facilities. The standards development process was also explained, including that the IIAR standards committee comprises representatives of all aspects of the industry including end-users, manufacturers, contractors, consultants and other interested parties.

Staff also met with the Significant New Alternatives Policy (SNAP) Team, which reviews and determines which refrigerants can be used to satisfy EPA requirements. "This pertains to the phasing down of refrigerants that are harmful to the ozone and are harmful for global warming," Lundell explained. "Using lower global warming potential refrigerants, driven by the AIM Act, is accelerating the use and consideration of natural refrigerants with zero ODP and zero or very low GWP."

The IIAR HC standard that is in development is being written to address larger closed-circuit refrigeration systems that use natural hydrocarbons as the refrigerant. The systems being considered are beyond the size of the presently approved SNAP-listed equipment/systems. "IIAR hopes that the EPA will consider the standard as a basis for expanding the SNAP approval listings for natural hydrocarbon refrigerants such as propane, butane and isobutane," Lundell said.

Other achievements central to IIAR's mission include the well-marketed NRF Scholarship program, which had 30 applicants this year and awarded eight scholarships, and the openness within NRF to provide financial support to scholarships, conduct research projects, and create training, educational programs, guidelines and tools to aid the industry's practitioners.

"The NRF coffers have been building since the foundation's inception, thanks to the generous support of donors and good investment practices," Smith said. "While it is important to maintain and grow the fund, it is equally important to use it to accomplish the NRF and IIAR missions."

TECHNICAL PAPER #5

Carbon-Dioxide System Relief Sizing

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ABSTRACT

Generally, safety standards for refrigeration systems require the placement of at least one overpressureprotection device on all carbon-dioxide (R-744) systems as well as on vessels manufactured in accordance with the American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section VIII Division I, or the regional equivalent1,2. The standards contain equations for determining the required discharge capacity to relieve pressure caused by external heating for common pressurized system components in the form of a constant multiplied by an area, either projected or actual, specific to the equipment type. The constant in the equations, f, is based on the continuous and constant external radiative heating of two phases in equilibrium at the relieving pressure, allowing for boiling and assuming ideal-gas behavior to convert the boiling mass flow into standard-air flow. In practice, many carbon-dioxide refrigeration systems discharge under non-ideal conditions. Therefore, the underlying assumptions of the current standards do not apply to the real-world conditions that are anticipated for many, if not all, carbon-dioxide refrigeration systems. This study presents an overview with examples of a rigorous two-step isobaric—isentropic calculation method, commonly known as the homogenous direct integration method, to determine the overpressure-protection device maximum flow area for any carbon-dioxide relief condition that may be expected in refrigeration systems.

Summary

The sizing of overpressure-protection devices, which are required for discharging in various fluid states due to the pressure caused by external heating, has been well-described in the literature.[3] The published work contains background information concerning the inapplicability of relief sizing equations that are derived from ideal-gas assumptions because the fluid is not expected to be ideal, e.g., in the supercritical region, and describes a widely applicable, rigorous, isobaric–isentropic calculation method. The homogeneous direct integration (HDI) method can be applied to any homogenous equilibrium fluid that reduces pressure along an assumed isentropic path. The method identifies the maximum mass flux under the choked flow condition. Based on the expected mass flow rate, the maximum required relief device flow area can be calculated.

Herein, the HDI method is applied to closed carbon-dioxide systems discharging in the range of 5-20 MPa (700-3,000 psi).

The key to implementing the method is the availability of carbon-dioxide state properties, which can be obtained from the NIST *Reference Fluid Thermodynamic and Transport Properties Database (REFPROP)*.[4]

The results are presented in a form that can be readily used by industry practitioners worldwide and potentially included in future editions of safety standards.

System Under Consideration

The case considered here is a closed (blocked-in) vessel containing carbon dioxide subjected to an external heating rate of Q = 1.0 kJ/s. This Q value is used for simplicity and subsequent application in any desired basis relationship to determine external heating loads. Calculations are performed at the discharge pressures, ignoring any potential inaccuracy in the device caused by dynamic effects that may occur during device operation, such as potential relief valve chatter or pressure accumulation in the system. Heat transfer effects, such as vessel shell conduction or inefficiency in internal vessel-surface heat transfer, are also neglected. The carbon dioxide is assumed to remain in thermodynamic equilibrium, ignoring any boiling or condensation delay effects. Liquid and vapor phases have the same velocity, and we only consider the no-slip condition. Lastly, no flow area coefficients are included.

Regardless of the initial process conditions, the closed vessel contents are externally heated at the fixed vessel volume, i.e., isochorically, until reaching the relieving pressure. Step 1, the first calculation step of the method, occurs while constant heating is continued at the constant relieving pressure, i.e., isobarically. Step 2, the second calculation step, occurs while the fluid depressurizes at constant entropy, i.e., isentropically. The solution method is iterative, with the results of step 1 feeding into step 2, which returns for refinements of step 1.

Step 1: Isobaric Process at Relieving Pressure

After reaching the relieving pressure, the carbon dioxide continues heating, thus creating the relieving mass flow. This flow may be caused by boiling, if two phases exist, or from single-phase volumetric expansion from the constant vessel volume.

The boiling mass flow rate, which forms the basis of current safety standards, is given by the ratio of heating to the latent heat of vaporization for the relieving condition. For this expression, we can add the conventional correction term for volume change of the two phases during boiling in the fixed volume vessel,[5] which is neglected by many safety standards.[6]

$$M = \left(\frac{Q}{H_{fg}}\right)\left(\frac{v_g - v_f}{v_g}\right)$$

M = Mass relief rate (kg/s)

Q = Heating (kJ/s)

H_{fg} = Latent heat of vaporization (kJ/kg)

v = Specific volume (m^3/kg)

f = Liquid

g = Vapor

Volumetric expansion mass flow, applicable to any single-phase system, is given by[5]

$$M = \frac{Q \times \beta}{C_p}$$

β = Coefficient of volumetric expansion at constant pressure (K^{-1})

C_p = Specific heat at constant pressure (kJ/kg K)

As a preliminary first step for a two-phase system, it is important to determine whether boiling is the dominant mass flow process. Table 1 shows the two values with 1-kJ/s heating for the range of potential two-phase relieving pressures.

Relieving	Boiling	Volumetric
P (MPa)	M (kg/s)	M (kg/s)
7.0	0.0063	0.0083
6.5	0.0056	0.0083
6.0	0.0051	0.0083
5.5	0.0048	0.0082
5.0	0.0045	0.0081

Table 1. Comparison of the boiling and volumetric expansion mass flow rates over the range of potential two-phase systems using 1-kJ/s heating. The volumetric expansion mass flow rate dominates in all cases.

The results of the comparison are convenient because they suggest that volumetric expansion is the dominant source of mass flow, which determines the largest required flow area of the pressure-relief device. As a practical matter, this condition is considered for a vessel that has either exhausted the available liquid by boiling or does not produce a second phase at the relieving pressure.

With this result, all subsequent mass flow rates will be determined using the volumetric expansion approach.

The objective is to determine the maximum allowable flow area of the pressure-relief device, i.e., the flow area at the narrowest cross section when the pressure-relief device is fully open. It is now convenient to introduce the relationship between mass flow rate and flow area, i.e., the expression we intend to maximize,[7] which can be expressed as

$$A = \frac{M}{G}$$

A = Flow area (m^2)

G = Mass flux ($kg/s\text{-}m^2$)

In addition to the equations for flow area and mass flow, based on volumetric expansion, applicable to all systems under consideration, it is necessary to define the expression for the required mass flux.

Step 2: Isentropic Process of Depressurization

The fundamental equation for mass flux along a frictionless path follows Euler's equations of motion. For one-dimensional flow, the expression can be rendered in multiple forms, two of which are examined here. The first is[7]

$$udu = -\frac{dP}{\rho}$$

u = Velocity (m/s)

This yields

$$G = \rho_n \sqrt{-2 \int_{P_0}^{P_n} \frac{dP}{\rho}}$$

ρ_n = Density (kg/m^3)

P_n = Outlet pressure (Pa)

P_0 = Inlet pressure (Pa)

Unfortunately, the integral in the mass flux equation does not have a closed-form solution for non-ideal systems; therefore, a numerical integration technique must be applied. The mass flux equation can be numerically integrated by applying a finite difference method as

$$G = \rho_n \sqrt{-4 \sum_{P_0}^{P_n} \left(\frac{P_{i+1} - P_i}{\rho_{i+1} - \rho_i} \right)}$$

However, for adiabatic flow, a second form of the one-dimensional flow equation is also useful, which can be expressed as

$$udu = \quad - dH$$

This expression can also be integrated as

$$G = \rho_n \sqrt{- 2,000\left(H_n - H_0\right)}$$

H_n = Outlet enthalpy (kJ/kg)

H_0 = Inlet enthalpy (kJ/kg)

This second form is more general than the first because it is not restricted to only the isentropic case. However, though it is easier to implement computationally, the sensitivity to small variations in enthalpy means that the accuracy of the enthalpy values are more critical.

We evaluated the range of pressures using both forms and found no significant differences between the results. Therefore, moving forward, only the calculations and results based on this second adiabatic form are presented.

Calculations

The calculations were performed using Excel with a VBA script. The Excel REFPROP wrapper makes this platform particularly convenient.

Tables 2 and 3 provide representative outputs of the calculation method for the relieving pressure of 12 MPa.

T (K)	Sg (kJ/kg K)	Cp (kJ/kg K)	β (1/K)	M (kg/s)	G (kg/m² s)	A (mm²)
349.48						
349.49	1.72525	2.5373	0.01450	0.0057139	42,244.9	0.135255671
349.50	1.72532	2.5367	0.01449	0.0057134	42,241.2	0.135255670

Table 2. Step 1 results performed under isochoric and isobaric conditions for relief at constant vessel volume and pressure while external heating is continued. Temperature is increased by the iterative VBA script at 0.01-K intervals and 12 MPa of relieving pressure. Flow area and mass flux are shown in Table 3.

P (MPa)	H (kJ/kg)	ρ (kg/m³)	G (kg/m² s)
12.000	438.738579		
6.513	417.469330	204.825005	
6.512	417.464447	204.801500	42,244.877
6.511	417.459564	204.777993	42,244.876

P (MPa)	H (kJ/kg)	ρ (kg/m³)	G (kg/m² s)
12.000	438.763949		
6.513	417.491372	204.791272	
6.512	417.486489	204.767771	42,241.224
6.511	417.481605	204.744268	42,241.222

Table 3. Step 2 is performed under isentropic depressurization through the flow area. Pressure is decreased by the iterative VBA script at 1-kPa intervals until a maximum, which occurs at the choked condition, is found for each of the temperature step entropies produced in Table 2. The maximum mass flux values are subsequently returned to Table 2 for determination of the maximum flow area. The iteration is continued until the maximum flow area is returned in Table 2.

Table 2 shows the final position of the iteration for the relieving pressure of 12 MPa. The carbon-dioxide single-phase entropy at 12 MPa and 349.49 K is 1.72525 kJ/kg K. This entropy value informed the upper panel of Table 3, and the entropy value of 1.72532 informed the lower panel of Table 3.

Table 3 also shows the final position of the iteration for the case at 12 MPa. At the flow area pressure of 6.512 MPa, the top panel produced the maximum mass flux value of 42244.877 kg/m^2s, which was returned to Table 2. The bottom panel returned a value of 42241.224 kg/m^2s at 6.512 MPa, which was also returned to Table 2.

Returning to Table 2, the maximum mass flux values are used in conjunction with the calculated mass flow rate to calculate the associated flow areas. At the temperature of 349.49 K, flow area pressure of 6.512 MPa, relieving pressure of 12 MPa, and entropy of 1.72525 kJ/kg K, the maximum flow area of 0.135255671 m^2 was obtained.

Notably, all relationships are smooth and continuous, so maxima are easily identified, e.g., the decrease in Table 2 of the area in the final row or the decrease in mass flux in the final row for both Table 3 panels.

As a practical matter, in all cases, the maximum mass flux, which represents the choked flow condition, was found to be roughly 50% of the inlet pressure, as expected. This is important because this pressure should always be evaluated against any allowable back pressure constraints. Furthermore, it should be confirmed that the choke condition occurs at a pressure above the expected back pressure; if not, then choking will not occur. Table 4 shows the choke conditions calculated for the examined pressure range.

Relieving P (MPa)	Choke P (MPa)	Choke S (kJ/kg/K)	Quality x (kg/kg)
20.0	10.510	1.8064	Undefined
19.5	10.263	1.8023	Undefined
19.0	10.015	1.7981	Undefined
18.5	9.767	1.7937	Undefined
18.0	9.518	1.7892	Undefined
17.5	9.269	1.7846	Undefined
17.0	9.020	1.7798	Undefined
16.5	8.770	1.7749	Undefined
16.0	8.519	1.7698	Undefined
15.5	8.268	1.7646	Undefined
15.0	8.017	1.7593	Undefined
14.5	7.766	1.7539	Undefined
14.0	7.515	1.7483	Undefined
13.5	7.264	1.7427	Superheated
13.0	7.013	1.7370	Superheated
12.5	6.763	1.7311	Superheated
12.0	6.512	1.7253	Superheated
11.5	6.261	1.7192	Superheated
11.0	6.009	1.7128	Superheated
10.5	6.224	1.6682	0.9999
10.0	6.792	1.6124	0.9999
9.5	6.469	1.5942	0.8675
9.0	5.938	1.5902	0.7927
8.5	5.496	1.5884	0.7580
8.0	5.099	1.5883	0.7385
7.5	4.728	1.5929	0.7317
7.0	4.370	1.6120	0.7475
6.5	4.022	1.6365	0.7691
6.0	3.685	1.6614	0.7891
5.5	3.357	1.6844	0.8050
5.0	3.037	1.7048	0.8164

Table 4. Summary of the identified choke conditions for the pressures of 5 to 20 MPa based on 1 kJ/s of external heating. Quality was returned by REFPROP according to the conditions.

Finally, no formal error analysis was undertaken. However, the final results represent heating temperature steps of 0.01 K and depressurization steps of 1 kPa. A casual examination of the sensitivity from varying these factors indicates that the final temperature and pressure resolution is likely more than adequate. Additionally, as indicated earlier, results from the two forms of the mass flux equation produced nearly identical results. Deviations were much less than 1% under the lowest pressure conditions.

Results

Figure 1 summarizes the maximum flow areas for the range of relieving pressures.

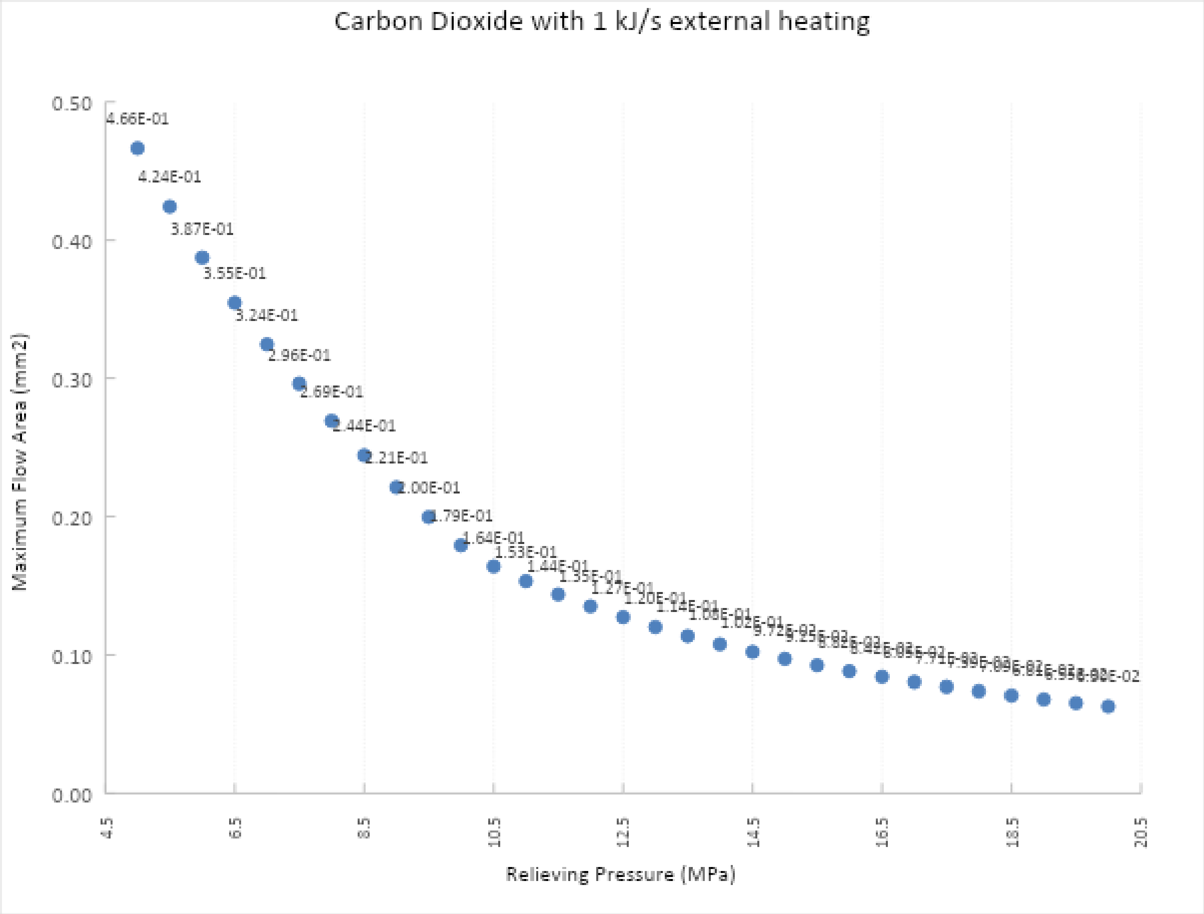

Figure 1. Maximum calculated flow areas for the relieving pressures of 5 to 20 MPa based on 1 kJ/s of external heating.

Application

The study was performed on a linearly scalable unit external heating basis of 1.0 kJ/s, making the results generalizable for any desired method of determining external heating.

Example 1: Consider a carbon-dioxide refrigeration vessel that is 2 m long and 0.5 m in diameter, relieving at 12 MPa. Based on the heating basis equation contained within the *IIAR CO_2 Standard* for Q = 28.39 kJ/s-m² applied over the projected area (length x diameter)[6] and the maximum flow area of 0.135 mm², which is shown in Figure 2 for relieving at 12 MPa, the required actual flow area is

$$A_{actual} = A \times Q \times [D \times L]A_{actual} =$$

$$\left(\frac{0.135\,mm^2}{\frac{1\,kJ}{s}}\right) \times \left(28.28\,\frac{kJ}{s\times m^2}\right) \times [(2.0\,m) \times (0.5\,m)]A_{actual} = 3.833\,mm^2$$

Example 2: Consider the same system but now refer to the European Standard – 378-2[2], which requires that Q = 10 kJ/s-m² is applied over the vessel's total surface area. Then, the required actual flow area is

$$A_{actual} = A \times Q \times \left[(\pi \times D \times L) + 2\left(\pi\frac{D^2}{4}\right)\right]A_{actual} =$$

$$\left(\frac{0.135\,mm^2}{\frac{1\,kJ}{s}}\right) \times \left(10\,\frac{kJ}{s\times m^2}\right) \times \left[(\pi\times 0.5m\times 2.0m) + 2\left(\pi\frac{0.5m^2}{4}\right)\right]A_{actual} = 4.241\,mm^2$$

Areas are also readily converted to standard-air flow rates, which is common for specifying devices in refrigeration services.

Example 3: Consider the system in the first example. To assist in specifying a relief valve, it is necessary to determine the required capacity for the mass flow rate of air at T = 293.15 K. We can use Fliegner's formula[8] for an ideal gas and assume a perfect nozzle, gas constant of R = 287.04 J/kg/K, and specific heat ratio for air of ϒ = 1.4. In addition, we must scale the result by applying the external heating Q = 28.39 kJ/s-m² over the projected area, i.e., length (m) x diameter (m), which can be expressed as

$$M_{standard\ air} = \left[\frac{A\times P}{\sqrt{T}} \times \sqrt{\frac{\gamma}{R}} \times \sqrt{\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}}\right] \times Q \times D \times L$$

$$M_{standard\ air} = \left[\frac{0.04042\times A\times P}{\sqrt{T}}\right]\times Q\times D\times L M_{standard\ air} = 0.109\,kg/s$$

Relieving P (MPa)	Flow Area (mm^2)	CO_2 Flow (kg/s)	Air Flow (kg/s)
20.0	6.299E-02	3.829E-03	2.974E-03
19.5	6.545E-02	3.908E-03	3.013E-03
19.0	6.808E-02	3.990E-03	3.054E-03
18.5	7.088E-02	4.077E-03	3.096E-03
18.0	7.387E-02	4.168E-03	3.139E-03
17.5	7.708E-02	4.263E-03	3.185E-03
17.0	8.053E-02	4.363E-03	3.232E-03
16.5	8.423E-02	4.469E-03	3.281E-03
16.0	8.821E-02	4.580E-03	3.332E-03
15.5	9.252E-02	4.697E-03	3.385E-03
15.0	9.718E-02	4.820E-03	3.441E-03
14.5	1.022E-01	4.950E-03	3.499E-03
14.0	1.077E-01	5.087E-03	3.560E-03
13.5	1.137E-01	5.232E-03	3.624E-03
13.0	1.202E-01	5.384E-03	3.690E-03
12.5	1.274E-01	5.545E-03	3.759E-03
12.0	1.353E-01	5.714E-03	3.832E-03
11.5	1.439E-01	5.892E-03	3.907E-03
11.0	1.535E-01	6.083E-03	3.986E-03
10.5	1.642E-01	6.554E-03	4.070E-03
10.0	1.795E-01	7.074E-03	4.238E-03
9.5	1.996E-01	7.387E-03	4.477E-03
9.0	2.212E-01	7.640E-03	4.700E-03
8.5	2.444E-01	7.879E-03	4.904E-03
8.0	2.694E-01	8.099E-03	5.088E-03
7.5	2.962E-01	8.274E-03	5.244E-03
7.0	3.245E-01	8.328E-03	5.362E-03
6.5	3.546E-01	8.309E-03	5.442E-03
6.0	3.874E-01	8.253E-03	5.488E-03
5.5	4.240E-01	8.181E-03	5.506E-03
5.0	4.664E-01	8.110E-03	5.505E-03

Table 5. Final results for the relieving pressures of 5 to 20 MPa based on 1 kJ/s of external heating. Flow area, carbon-dioxide mass flow rate, and standard-air mass flow rates are shown.

Conclusion

Table 5 shows the maximum flow area, mass flow rate of carbon dioxide, and mass flow rate of standard air evaluated on a unit external heating basis of 1 kJ/s for each relieving pressure. These values can help determine the discharge capacity in accordance with any of the safety standards, provided that their specific requirements are also considered.

To complete a required discharge capacity determination, depending on the chosen safety standard, the appropriate relieving pressure should be chosen based on the allowable pressure accumulation, typically 10% or 21% above the set pressure for most safety standards.

Then, the applicable safety standard format, mass flow of CO_2, mass flow of air, or flow area should be adjusted as shown in the examples for determining the equipment size and method of calculating the external heat load.

Finally, any other adjustments, such as the inclusion of discharge or capacity coefficients, should be included as required by the applicable safety standard or indicated by the device manufacturer.

With these simple arithmetic adjustments, the results are obtained in a form that is useful for industry practitioners worldwide and can be potentially included in future editions of any of the global refrigeration safety standards.

Appendix A: English units

Relieving P (psi)	Choke P (psi)	Choke S (Btu/lbm-R)	Quality x (kg/kg)
3,000	1,573.3	0.43304	Undefined
2,900	1,524.0	0.43171	Undefined
2,800	1,474.6	0.43037	Undefined
2,700	1,425.0	0.42895	Undefined
2,600	1,375.2	0.42745	Undefined
2,500	1,325.3	0.42593	Undefined
2,400	1,275.3	0.42433	Undefined
2,300	1,225.2	0.42265	Undefined
2,200	1,175.0	0.42092	Undefined
2,100	1,124.7	0.41914	Undefined
2,000	1,074.5	0.41728	Undefined
1,900	1,024.4	0.41541	Superheated
1,800	974.4	0.41350	Superheated
1,700	924.2	0.41155	Superheated
1,600	873.8	0.40947	Superheated
1,500	930.5	0.39476	Superheated
1,400	968.5	0.38138	0.9158
1,300	856.3	0.38003	0.7894
1,200	770.4	0.37961	0.7481
1,100	694.7	0.38033	0.7314
1,000	623.1	0.38649	0.7521
900	554.4	0.39469	0.7814
800	488.3	0.40245	0.8047
700	424.6	0.40892	0.8190

Table A6. Summary of the identified choke conditions for the pressures of 700 to 3,000 psi based on 1 Btu/s of external heating. Temperature steps of 0.02 °F and pressure steps of 0.15 psi were used. Quality was returned by REFPROP based on the conditions.

Relieving P (psi)	Flow Area (ft^2)	CO_2 Flow (lbm/s)	Air Flow (lbm/min)
3,000	6.791E-07	8.664E-03	4.075E-01
2,900	7.149E-07	8.904E-03	4.147E-01
2,800	7.539E-07	9.158E-03	4.223E-01
2,700	7.966E-07	9.429E-03	4.302E-01
2,600	8.433E-07	9.721E-03	4.386E-01
2,500	8.947E-07	1.003E-02	4.474E-01
2,400	9.515E-07	1.036E-02	4.567E-01
2,300	1.014E-06	1.072E-02	4.666E-01
2,200	1.084E-06	1.111E-02	4.771E-01
2,100	1.162E-06	1.152E-02	4.882E-01
2,000	1.250E-06	1.197E-02	5.000E-01
1,900	1.349E-06	1.244E-02	5.126E-01
1,800	1.461E-06	1.296E-02	5.259E-01
1,700	1.588E-06	1.351E-02	5.400E-01
1,600	1.734E-06	1.411E-02	5.550E-01
1,500	1.911E-06	1.561E-02	5.733E-01
1,400	2.193E-06	1.699E-02	6.140E-01
1,300	2.529E-06	1.780E-02	6.575E-01
1,200	2.898E-06	1.855E-02	6.957E-01
1,100	3.308E-06	1.918E-02	7.278E-01
1,000	3.751E-06	1.936E-02	7.503E-01
900	4.238E-06	1.924E-02	7.630E-01
800	4.797E-06	1.902E-02	7.676E-01
700	5.480E-06	1.881E-02	7.672E-01

Table A7. Final results for the relieving pressures of 700 to 3,000 psi on a 1-BTU/s external heating basis. Temperature steps of 0.02 °F and pressure steps of 0.15 psi were used. Flow area, carbon-dioxide mass flow rate, and standard-air mass flow rates are shown.

Example A1: Consider a carbon-dioxide refrigeration vessel that is 2 ft long and 0.5 ft in diameter, relieving at 1,700 psi. To assist in specifying a relief valve, we must determine the required capacity in the mass flow rate of standard air. Based on the heating basis equation contained within the *IIAR CO_2 Standard* for Q = 150 Btu/min-ft^2 applied over the projected area (length x diameter)[6] and the standard-air flow rate of 0.54 lbm/min shown in Table A7 for 1,700 psi, which was calculated based on 1 Btu/s, the required capacity is

$$C = \left[M_{air}\right] \times [Q] \times [D \times L] C = \left[\frac{\frac{0.54\, lbm_{air}}{min}}{\frac{1\, Btu}{s}}\right] \times \left[\left(150\, \frac{Btu}{min \times ft^2}\right) \times \left(\frac{min}{60s}\right)\right] \times [(2.0\, ft) \times (0.5\, ft)] C = 1.35\, \frac{lbm_{air}}{min}$$

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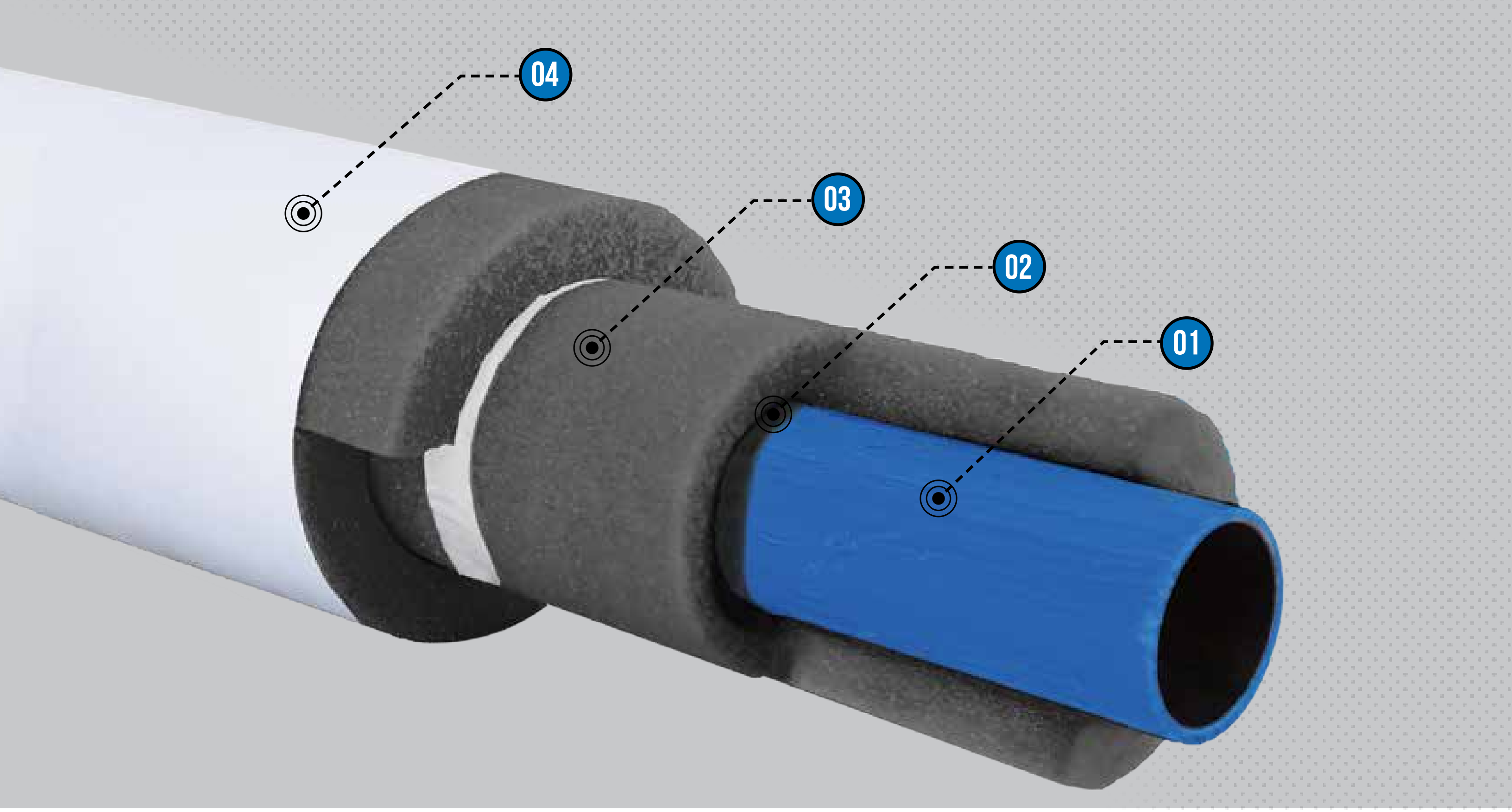

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