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NRF RESEARCH VALIDATES CO_2 STANDARD

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WINTER 2026

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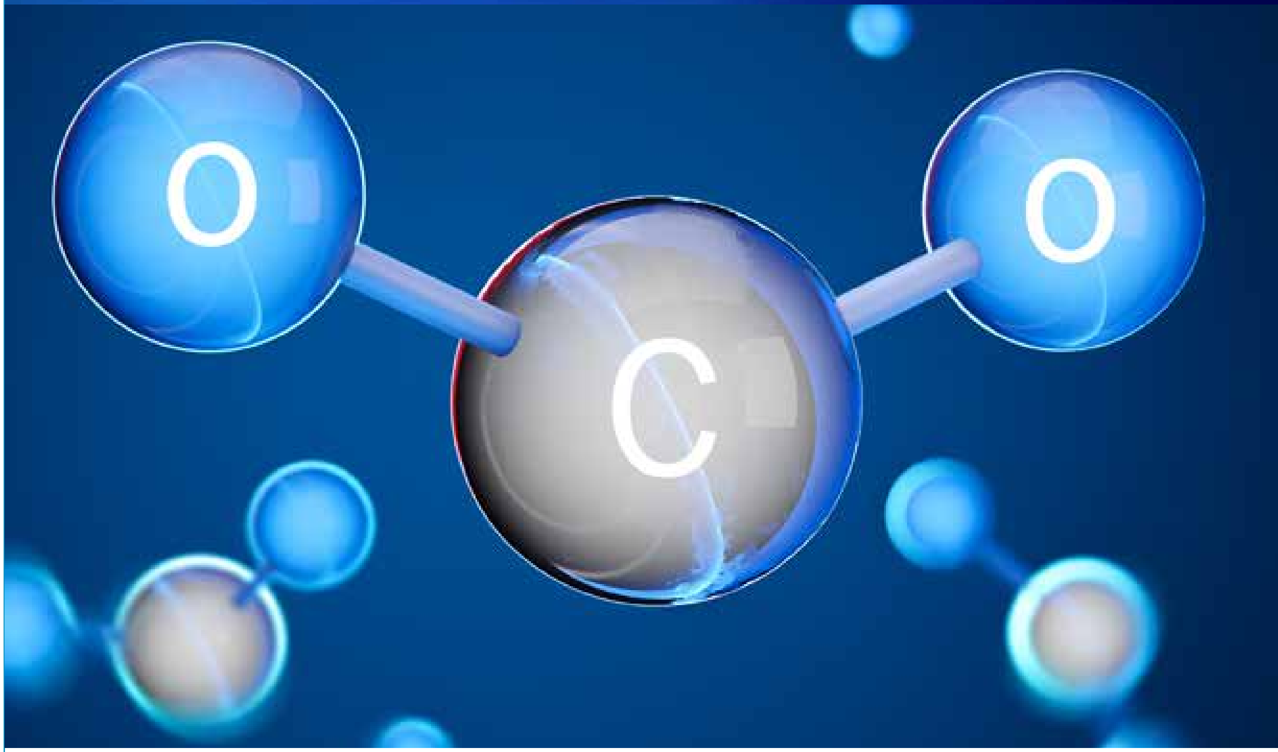
06 COVER story

NRF Research Validates CO_2 Standard



Welcome to San Antonio and the 2026 IIAR Industrial Refrigeration Conference & Heavy Equipment Expo!

Welcome IIAR members and guests to the 48th IIAR conference, and welcome to San Antonio. While we're still two years away from our truly historic 50th anniversary, I'd argue we're entitled to start celebrating now. So much of the work we, and IIAR's past leaders, have put into advancing natural refrigeration, is paying off these days. And so much of that work began each year, right here at our annual conference. I'm honored to kick off yet another week of goal setting, moving big projects forward, meeting new and old friends, and spotting the new opportunities that several decades of work on behalf of our industry has materialized.

First, I want to highlight the importance of that technical and advocacy work – and encourage anyone who gets the chance to attend our committee meetings on Sunday – to go! As an IIAR member, you can get directly involved in the work of our organization. Our biggest strength is your talent. Whether it's technical expertise, new viewpoints or a particular skillset you can contribute, IIAR committees need your time and volunteer leadership.

This year, our NRF lounge will be open again, this time throughout the conference, continuing a tradition started last year to help our NRF scholarship recipients' network and highlight the exciting research work being advanced by our foundation. Meanwhile, our IIAR staff will be showcasing a new conference scheduling structure they've worked hard to create this year – which allows for several chances to see the same session. This will allow for more time in the exhibit hall and more time to really get the most out of our technical program.

The standout technical session this year will be our closing forum, in an interactive format that's a new addition to the conference. If there's anything you ever wanted to know about IIAR's standards, this closing session will be the place to be. We'll have the subcommittees and current leads on all our standards present to take questions, give perspective and even challenge the audience. Answers to all your questions (and prizes to be won in the process) are on deck!

If you're an end user with people in technical fields who need to understand IIAR's role or just a member passionate about our standards, this will be a great event to use to educate or be educated on the work IIAR is doing in our industry.

As usual, our opening keynote session merits some discussion. Delivered this year by evolutionary biologist and stress expert, Dr. Rebecca Heiss, the talk will focus on how to attract and retain talent in the competitive world of work.

And of course, no welcome message would be complete without mentioning our social outing, which I am especially excited about this year. Make sure you don't miss Pedrottis Ranch where you can brush up on your rodeo skills or just enjoy the live music under a canopy of Texas live oak trees.

I want to give a huge shoutout to your IIAR staff whose hard work makes this gathering possible. Welcome to San Antonio and enjoy the conference!

Best Regards,
Lesley Schafer
2026 Conference Chair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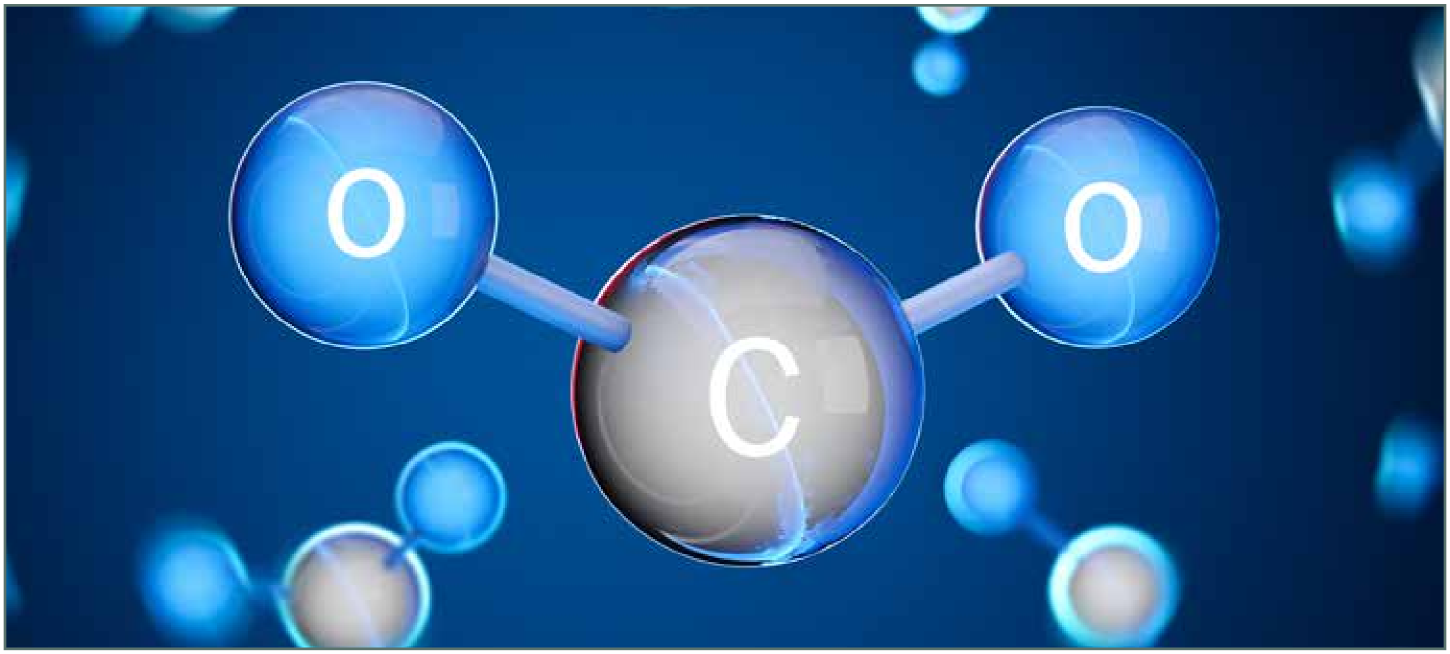
NRF Research Validates CO_2 Standard



A new research project funded by IIAR's Natural Refrigeration Foundation has validated a key calculation used in the ANSI/IIAR CO_2-2021 Safety Standard for Closed-Circuit Carbon Dioxide Refrigeration Systems.

The calculation is used to generate a formula that determines the CO_2 relief valve sizing recommendations in the CO_2 safety standard. While the validation of that formula provides valuable data for IIAR, it emerged from the early phases of a larger research project focused on the behavior of CO_2 in a supercritical state – a project currently underway at the University of California, Berkeley.

"This is very exciting for us because how often do we get the chance to do the science unique to our industry that validates the real data behind a standard?" said Bill Greulich, Chair of the IIAR Research Committee.

"Right off the bat, Berkeley has validated our CO_2 standard with our test equipment. We're already getting real data, and our vessel is already operating outside the historical ASHRAE description of CO_2" which assumes subcritical conditions.

The project is funding doctoral candidate work on CO_2's behavior in a supercritical state, primarily to determine why dry ice may form in overpressure protection systems during standstill events, where CO_2's low critical temperature and high triple point pressure create unique pressure conditions.

"We need to understand the formation of dry ice in relief piping during these events," said Bruce Nelson, IIAR's past Chairman. "CO_2 is a very unusual refrigerant, very unlike other working fluids that we use as natural refrigerants. It is a tremendous and useful refrigerant, but it doesn't behave itself in certain cases and has to be treated differently."

"Observing and understanding these differences will help us improve design and safety practices, which is the reason we're doing this research," he said, adding that IIAR was fortunate in identifying UC Berkeley as having the background and qualifications to partner with NRF to do the work.

The project "will look to advance some fundamentals of the deep pressurization process for CO_2," said Greulich, adding that the initial validation of the data behind IIAR's CO_2 standard came out of a small-scale experiment that is being used to finish the initial benchmarking work required to build a larger testing laboratory.

"It's in that testing that we're seeing validations," said Greulich. "As we're building up to the full experiment, we have to make sure we fine-tune our ability to understand the inlet conditions [of the test vessel], and it's in that process that we're seeing the first data."

"Right at the beginning of this process, we got a critical piece of data, the mass flow rate over time. It's that data that validates the approach we've used in the CO_2 standard."

The mass flow rate over time is the calculation that underpins the equation, called the capacity calculation, that IIAR uses to generate the latest version of the CO_2 relief valve sizing formula that appears in the CO_2 standard.

For those unfamiliar with the fluid dynamics of CO_2, the significance of validating something as basic as a capacity calculation may not seem like much of a big deal. However, the implications this validation has for advancing the CO_2 safety standard – and the opportunities it presents to the industry – are significant, said Greulich.

"CO_2 is a very interesting refrigerant, it's different than the refrigerants we're used to working with, that we operate in a sort of normal physics range," he said. "CO_2 is in a kind of fourth state of matter in high pressure, it's in none of these three states, it's in a supercritical state where it's both gas and liquid."

"Supercritical fluids behave in interesting ways [that we don't fully understand], that's why the current ASHRAE-15 guidance

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on sizing relief valves was based on CO_2 operating in 'normal' conditions, not in a supercritical state," said Greulich.

The new data Berkeley generated describes CO_2 in a supercritical state, validating the science behind the capacity calculation with an actual observation.

Nelson said the new data generated by the project may help IIAR and ASHRAE harmonize CO_2 standards, but the overarching goal is to improve design practices for CO_2 systems.

"With this project, we've already learned some very interesting things about CO_2. We don't know all the answers yet, but this project will hopefully provide us with the answers that will make their way into our safety standards."

Currently, "there's a gap in our knowledge and a need for research that results directly from two characteristics of CO_2," said Nelson.

First is the low critical temperature of CO_2, at 88 degrees Fahrenheit, the point at which the distinction between CO_2 liquid and vapor disappears.

Second is the high triple point pressure of CO_2, at ~75 psi. The triple point is the point at which liquid, vapor, and solid can all coexist.

"The challenge with CO_2 is the low critical temperature and high triple point pressure," said Nelson.

"The reason we're doing this research and the potential problem we don't fully understand has to do with this high triple point pressure. A potential problem arises when you have a vessel that contains liquid and vapor under normal operating conditions that has a safety relief set point that is at a supercritical pressure."

"In this case, the possibility exists for dry ice to form in the safety relief piping during a relief event. We don't really know when and how this dry ice might form – it's unpredictable, and we really don't fully understand the physics at play yet."

While the Berkeley research project is specifically focused on answering that question, the significance of the NRF-funded research may have implications beyond natural refrigeration.

"There's room here to advance the state of knowledge around supercritical fluids in general," said Greulich, adding that the project is an opportunity to advance the entire knowledge base of CO_2.

The next phase of the project will be to build the final 160L vessel, said Greulich. "That's ultimately the vessel that will anchor the high-pressure rig for CO_2. Once this vessel comes online with all the validating data from the 53L test vessel, that will be where the rubber meets the road on this project."

"We're close to one year in with Berkeley on this work, and we're finishing up the validation now," he said. "In the coming year, we will really get into the icing piece of the project."

While the project is exciting for its potential to expand what is known about CO_2, the new data will be timely, considering the evolution of current CO_2 system design, said Nelson.

"One thing that is happening in our industry is that standstill design pressures for these CO_2 systems are increasing."

Initially, design pressures on transcritical CO_2 systems were in the range of about 750 psia, but as the transcritical CO_2 industry has evolved, the design pressures to handle standstill systems have increased from approximately 700 psia to 1700 psia.

"There are many systems today that are going in with some very high standstill design pressures to avoid a loss of refrigerant during a standstill pressure event," said Nelson. "And the potential loss of refrigerant during those standstill events is another big challenge."

That goes back to why IIAR is doing this research, he said. "At the higher relief setpoints that we're seeing in the market, the possibility exists for dry ice to form and lead to unpredictability in relief piping."

As higher design pressures become the norm, "understanding when and how dry ice might form will lead IIAR to develop safer practices for these relief piping systems," said Eric Smith, Vice President and Technical Director for IIAR. "This project is promising for its potential to establish definitive resources for CO_2 safety." He added that the progress of the new research will be presented at the upcoming IIAR annual conference, March 15-18 this year.

IIAR RESEARCH PROJECT WORK STATEMENT

Title: Characterization of carbon dioxide deposition and blockage in individual pipes and relief headers

Authors: T. M. Schutzius, V. P. Carey - University of California, Berkeley

Executive Summary: Industrial refrigeration systems require overpressure protection, but for CO_2 there is a risk of solid deposition and pipe blockage during pressure relief leading to serious safety concerns [1]. Design guidelines exist for pressure relief valve capacity determination [2], however, we lack clear guidelines for installing multiple relief valves from different vessels feeding into a common manifold. This is because the relationship between thermodynamic state, heating loads, and relieving vessels on deposition is unknown. We will use experimental and theoretical methods to create phase-maps that highlight ice deposition-prone areas in relief valve-manifold connected systems assisting engineers in designing safer overpressure protection systems.

Justification and Value to IIAR: Reliable predictions of CO_2 deposition in pressure relief systems are of value to any IIAR member designing CO_2 systems.

Objectives:

> We will quantify experimentally the diameter, concentration, velocity, and phase fraction of CO_2 ice generated at the exit of a pressure relief valve or nozzle and its deposition behavior in single pressure relief lines.

> Determine the critical vapor velocity and shear stress where CO_2 ice crystals sediment, creating a blockage hazard.

> Using numerical simulations, quantify the deposition behavior of initially entrained CO_2 particles within flowing vapor within downstream pressure relief lines and headers.

> Regions of CO_2 ice deposition determined from numerical simulations will then be studied experimentally and rationalized using first principles and dimensional analysis. Recommendations for best practice in pressure relief system design will be provided and demonstrated experimentally and numerically.

> Quantify for a given pressure relief system how much liquid CO_2 can be blown off before the system becomes blocked.

Ammonia Refrigeration a ‘Century-Proof’ Technology

Proven in Early Systems, Ammonia Still Meets Modern Performance & Regulatory Demands

In 1926, ammonia was the dominant refrigerant for large-scale refrigeration applications. Leading up to that point, ammonia refrigeration played a key role in the industrial revolution, earning itself, along with other natural refrigerants, a reputation for being a “century-proof” technology.

Spanning the late 1800s, when steam engines gave rise to the first basic mechanical refrigeration systems -- to 2026, when natural refrigerants and specialized equipment are able to deliver precise temperature control -- the natural refrigeration industry underpins many of the most important advancements of modern life.

Chief among them is the creation of the global cold chain, which feeds the world’s population. And while the cold chain that developed in the 1930s through the 1960s was instrumental in the advancement of food manufacturing in its time, the pressure to maintain and expand that system to feed the world is driving innovation today.

LOOKING BACK

To understand the demands of the worldwide refrigeration systems built on natural refrigerants, one must first understand their past. Prior to the invention of synthetic refrigerants -- and even after -- natural refrigerants remained a simpler and more environmentally responsible technology, shaped over time by competition with ozone-depleting and, more recently, PFAS-based synthetics.

The most significant technical and safety milestones in ammonia system design over the past century were driven first by the needs of food production, and later by safety and environmental regulations.

In the late 1800s and early 1900s, industrial ammonia refrigeration was the dominant cooling technology, first used in meatpacking and breweries as well as transportation, where ice was made to ship meat and vegetables in boxcars.

“Ammonia systems were first applicable to food production – primarily by enabling the first cold storage facilities, which laid the foundation for the industry and the beginning of a global cold chain,” said Kent Anderson, president emeritus of the International Institute of All-Natural Refrigeration (IIAR).

Mechanical refrigeration allowed ice to be made anywhere, but it was mostly a localized effort to support meatpacking and breweries. That changed in the 1920s when electric motors and the advancement of reciprocating compressors made refrigeration plausible on an industrial scale and gave rise to the first big food processing plants.

By the late 1950s, the industry was undergoing another technology change with a shift towards more compact equipment, the development of hermetic motors, and then screw compressors in the mid 1960’s. “These were significant technology innovations, because for the first time you could deliver large capacity with compact equipment,” said Anderson.

That development led to a proliferation of ammonia systems in cold storage and ushered in an era of mass food production in the 1950s. “In the 1950s and 1960s, the development of frozen food products changed the entire cold chain,” said Anderson. “Ammonia refrigeration was critical in the manufacture of frozen food and cold storage, and the changes in the way we produced food led to an evolution of the cold chain.”

The ability to produce, process, and store food on a mass scale in turn, led to another big shift in refrigeration – the widespread use of “freon” refrigerants in grocery stores, trucking, and other parts of the industry.

By the late 1960s and early 1970s the forces shaping industrial refrigeration were largely operational rather than mechanical. Some food manufacturing and distribution companies began using commercial-grade, factory-built, synthetic refrigerant systems because they were inexpensive and did not require specialists for installation, operation, and maintenance. They were also considered to be safer than ammonia-based systems. However, most large-scale operations continued to use ammonia, because it is highly energy efficient and offers advantages such as tolerance for water contamination, easy detection, and low initial refrigerant costs.

SAFETY AND STANDARDS

A series of high-profile incidents involving lethal releases of toxic chemicals gave rise to safety and environmental scrutiny from the newly formed Occupational Safety and Health Administration (OSHA) and the Environmental Protection Agency (EPA).

By the late 1970s and early 1980s, the industry’s first formal foundation of a safety framework -- in the form of Process Safety Management -- had emerged. Then in 1990, ammonia was specifically mentioned in legislation that updated the Clean Air Act, officially regulating the chemical and scooping up industrial refrigeration with it. The result was that refrigeration systems with large quantities of ammonia were then regulated by both OSHA and the EPA under Process Safety Management and Risk Management Programs, respectively.

While IIAR, the ammonia refrigeration industry’s standard-creation and advocacy organization already existed, it was this language in the 1990 amendment of the Clean Air Act that catapulted the group to the forefront of safety and started a new era in industrial refrigeration: one in which the dominant technology was to be shaped by safety and efficiency.

“The original founders of IIAR saw that a need and an opportunity existed for the industry to define safety,” said Anderson. “One of the most important things IIAR did was develop specific industry guidelines to meet the requirements of broad-based industry regulations. IIAR had a plan everybody could follow. That was a good thing for our industry, and it brought more attention to safety.”

He added that, “IIAR-2 was first a standard developed to deal with code issues. But because safety became a primary concern, the standard has grown from 10 to over 70 pages, incorporating the best engineering practices for ammonia refrigeration. More engineering controls and safety measures were put into IIAR-2 as a voluntary consensus standard, and now, rather than the government arbitrarily applying regulations to the industry regulators direct

AMMONIA REFRIGERATION A 'CENTURY-PROOF' TECHNOLOGY (continued from page 8)

companies to follow IIAR-2 and other related IIAR standards."

The opportunity that IIAR took in the 1990s to become the leader in creating and establishing the industry's safety standards -- which have now grown into a suite of 11 standards -- laid another foundation for advancement, by defining where and how natural refrigeration systems could be used safely, said IIAR president, Gary Schrift.

ENVIRONMENTAL CONCERNS

While all this was happening in the large-scale, ammonia-based industrial refrigeration industry, the synthetic refrigerant industry was undergoing its own evolution. Beginning in the 1960s, scientists began noticing that the atmosphere's ozone layer was shrinking. Evidence eventually led to the understanding that chlorinated refrigerants were the leading cause of ozone depletion.

By the 1990s, CFC and HCFC refrigerants were being phased out worldwide, and regulations on handling and managing these refrigerants were implemented. Soon after, more research revealed that the HFC replacements for CFC and HCFC refrigerants were leading contributors to the greenhouse gas effect.

By the middle of the 2010s, many high-GWP refrigerants began to be phased out, and the synthetic refrigerant industry began marketing new HFCs and HFOs with lower-GWP values. Many who had embraced synthetic refrigerants began to turn back to ammonia and other natural refrigerants as it became clear that they were the most reliable alternatives to ozone-damaging CFC and HCFC refrigerants and high-GWP replacements.

"Regulations around risk management, efforts to reduce emissions in general, and the EPA's phasedown of CFCs and HFCs have created a demand for more advanced, more efficient systems," said Schrift. "This has highlighted the central role natural refrigerants play as the most viable refrigeration option focused on safety, which has driven innovation over much of the last decade."

Two of the biggest technology evolutions – a shift to low-charge ammonia refrigeration systems and a focus on the development of CO_2 systems -– have yielded more advanced systems that, thanks to IIAR's safety standards, are poised to meet the environmental, regulatory, efficiency, and safety challenges of the future.

This technical versatility has enabled natural refrigerants to move beyond traditional use cases, and they now support complex climate control systems in data centers; contribute to waste heat recovery in district energy networks; and improve thermal management across industrial manufacturing processes.

The industry is already moving towards its next major evolution, said Schrift, who compared the growing concern over PFAS pollution risk posed by new synthetic HFO refrigerants to the realization in the 1970s that synthetic refrigerants were destroying the Earth's atmosphere. "As people start to recognize the environmental and regulatory uncertainty that accompany synthetic refrigerants, it will be clearer than ever that ammonia, CO_2, and other naturals are the best way forward."

Fortunately, he said, the industry is prepared. "Our history has shaped and refined these technologies over almost a century of responding to safety and design challenges, whether because of regulation or because new applications have demanded better solutions. The result is that we have a solid foundation for safety, efficiency, and economy. And that foundation enables innovation to happen fast when the world needs us to respond to the biggest human and environmental challenges of the future."

GOVERNMENT RELATIONS

BY LOWELL RANDEL, IIAR GOVERNMENT RELATIONS DIRECTOR

OSHA Announces New "Safety Champions" Voluntary Program

In January 2026, the Occupational Safety and Health Administration (OSHA) announced the creation of a new voluntary program called Safety Champions which has been added to the suite of cooperative programs (such as the OSHA Challenge and Voluntary Protection Program) administered by the agency.

Safety Champions is designed to help employers develop and implement an effective safety and health program to help prevent workplace injuries, illnesses, and deaths. The program is free and participants can advance through the program at their own pace. The addition of a new voluntary program is consistent with the Trump Administration's increased emphasis on cooperative programs and compliance assistance.

The Safety Champions Program focuses heavily on the seven core elements of OSHA's Recommended Practices for Safety and Health Programs. Many IIAR members are already implementing these principles as a part of their compliance efforts under Process Safety Management (PSM) and Risk Management Program (RMP) related to their refrigeration systems. However, these principles also apply outside of refrigeration and this program could be helpful for facilities to make sure they are appropriately addressing a broad range of safety and health hazards that may be present in their facilities.

The seven elements of OSHA's Recommended Practices for Safety and Health Programs are:

MANAGEMENT LEADERSHIP

Leadership commitment from top management is essential. This includes setting safety goals, allocating resources, and integrating safety and health into business operations. Leaders should be visibly involved and accountable for the program's success.

WORKER PARTICIPATION

Workers at all levels, including contractors and temporary employees, should be actively involved in the safety program — from identifying hazards to developing solutions and reporting potential concerns.

HAZARD IDENTIFICATION AND ASSESSMENT

Employers should identify workplace hazards — through audits, risk assessments, incident data reviews, and worker input.

HAZARD PREVENTION AND CONTROL

Once hazards are recognized, practical methods should be implemented to eliminate or control them (e.g., engineering controls, administrative changes, PPE). The effectiveness of these actions should be tracked and verified.

EDUCATION AND TRAINING

All employees should receive training on how the safety program works, their roles in it, and how to recognize and control hazards. Supervisors and managers should be trained on leadership and responsibilities under the program.

PROGRAM EVALUATION AND IMPROVEMENT

Employers should regularly monitor and assess how well the safety program is working — looking at performance metrics, inspections, and worker feedback — and make improvements where necessary.

COMMUNICATION AND COORDINATION FOR MULTI-EMPLOYER WORKPLACES

When work involves multiple employers (e.g., host employers, contractors, staffing agencies), communication and coordination is important to ensure workers understand the safety program.

THREE PROGRESSIVE PROGRAM LEVELS

The Safety Champion Program has three levels (Introductory, Intermediate, and Advanced) to help employers advance their safety and health efforts. The levels are self-guided, and participants may work at their own pace. Employers can assess their current practices, identify gaps, and implement improvements incrementally. This structure is intended to make the program accessible to organizations of all sizes.

The three levels are:

Introductory: participants begin by assessing their current safety and health practices against the seven recommended elements. This involves identifying gaps and starting to implement foundational safety program components.

Intermediate: Organizations build on the basics to strengthen hazard prevention and control, increase worker participation, and deepen integration of safety processes. At this stage, safety activities become more comprehensive and structured.

Advanced: Participants integrate all core elements into organizational culture and operations, demonstrating sustained

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commitment and more mature systems. This step reflects a high-level safety program where practices are embedded across the organization.

SPECIAL GOVERNMENT EMPLOYEE (SGE) ASSESSMENTS

Another feature of the Safety Champions Programs is the ability for participants to request a Special Government Employee (SGE) Assessment. This is a non-enforcement assessment where an experienced safety and health professional is authorized to review employer safety programs and provide feedback on program effectiveness and progression. SGE assessments may include: an evaluation of safety policies and procedures; review of hazard assessments and controls, assessment of education and training, and input on how the safety program aligns with OSHA's Recommended Practices for Safety and Health Programs. Similar to the OSHA Consultation Program, an SGE assessment can help employers identify weaknesses in a facilities safety and health program before they result in citations or incidents.

The Safety Champions Program is a tool that can complement ongoing safety programs. It is not a substitute for following OSHA regulations such as PSM or IIAR standards. However, participation in the program can aid in identifying potential compliance gaps, improve audit/inspection readiness and strengthen safety culture. More information on the Safety Champions Program, including how to register, can be found at: https://www.osha.gov/safety-champions.

Similar to the OSHA Consultation Program, an SGE assessment can help employers identify weaknesses in a facilities safety and health program before they result in citations or incidents.

IIAR adds Resource Center in 2025, Begins Analysis of US Ammonia System Regulations

IIAR began a closer examination of the federal General Duty clause, Process Safety Management and Risk Management programs for ammonia refrigeration systems, built a new website section to highlight member resources, automated its peer review process for technical papers, and expanded events in Latin America in 2025.

In addition, IIAR also completed updates to four major publications: The Piping Handbook; IIAR 5-2025; IIAR 6-2025; and IIAR 7-2025.

These IIAR accomplishments will strengthen membership and educational offerings, and further its mission and advocacy for expanding the safe use of natural refrigerants in all countries.

"I'm always impressed by the amount of work IIAR committees and staff are able to churn out," said IIAR president Gary Schrift, adding that one of 2025's most significant projects – the new IIAR resources center website – was created to showcase all that work in one place.

IIAR RESOURCES CENTER

"It's incredible how many resources we've developed over the years. Whether they're technical (our codes and standards effort), educational, or oriented around communicating the value of natural refrigerants, they form the bedrock of what we do as an organization." Schrift said. "The new resource center site is a central place for everyone to quickly access what they need, whether it's a deep dive into a particular technical issue or information that gives someone a primer on our industry."

The new site consolidates IIAR's magazine and all its resources in one place, marking a significant shift for the organization, which has traditionally lacked a central communications hub.

"Our goal is simple: to ensure that every member, partner, and stakeholder throughout the world can easily find and use the tools that support their work. Many of our most valuable resources—hosted on IIAR and NRF pages—have historically been difficult to locate," said Schrift. "We're changing that. The redesigned resource site will serve as a centralized hub, linking directly to existing and a large amount of new content developed in 2025."

The new site includes:

• **Informational Papers**:: including the State of the Industry reports, refrigerant fact sheets, and a new PFAS Refrigerants white paper – along with future informational sheets and papers as they're produced.

• **Informational Videos**: featuring foundational content about IIAR, natural refrigerants, and the NRF, plus new promotional videos focused on CO_2, decarbonization, hydrocarbons, and ammonia.

• **Natural Refrigeration Career Center**: offering a public-facing job board listing internship and entry-level job openings of our members to connect talent with opportunity across our growing sector.

IIAR ANALYSES PSM/RMP, ADDS RESOURCE CENTER IN 2025 , BEGINS ANALYSIS OF US AMMONIA SYSTEM REGULATIONS (continued from page 15)

- **Natural Refrigeration Directory**: offering a public-facing and searchable listing of manufacturers, contractors, engineers, consultants, and end users who are experts in the use of natural refrigerants.

- **Natural Refrigeration Training Programs**: offering a public-facing, detailed, and searchable listing of training programs available for natural refrigeration.

- **Refrigerant Evaluator Tool**: offering a public-facing online tool that will assess and compare all refrigerants, synthetic and natural, by providing information on the refrigerants' chemical make-up, GWP, ODP, safety class, flammability, toxicity, thermodynamic properties, relative efficiency & USA EPA SNAP approval.

- **Ammonia Refrigeration Global Standards & Regulations**: offering a one-stop location to learn which standards and regulations apply for countries throughout the world.

- **Magazine Access**: with a direct link to our newly rebranded publication, Natural Refrigeration Review—formerly Condenser Magazine.

PSM RMP GAP ANALYSIS

Meanwhile, IIAR's newly formed "NORM" (Nh3 Overdue Regulation Modernization) task force started work last year to create a gap analysis matrix comparing the nine IIAR Ammonia standards and their requirements to the requirements of OSHA Process Safety Management and EPA Risk Management programs.

The gap analysis will eventually be a tool IIAR members can use to visualize the areas where IIAR standards are more stringent than the federal government, and conversely, where the federal government requires more than IIAR standards.

"This gap analysis will reveal the areas where the US federal government is asking for more than our standard, and vice versa," said Schrift. "The potential end goal is to create a simplified road map showing that if the IIAR standards are followed and you fulfill these few PSM/RPM requirements, you will have an extremely safe and regulation compliant ammonia refrigeration system in the USA. Currently one has to attempt to read and comply with the IIAR standards, the OSHA PSM and General Duty clause regulations, and the EPA RMP and General Duty clause regulations pertaining to ammonia refrigeration systems with many overlapping or duplicate requirements and some, in my belief, unnecessary and no-value requirements of the federal government regulations. . . That by the way do not apply to ammonia use in agriculture, a much larger use of ammonia in the USA and the world".

ORGANIZATIONAL IMPROVEMENTS

IIAR made several process updates to its organizational functions in 2025. First among them was an update of IIAR's conference technical and white paper submissions from a manual process to an interactive interface. Using Open Water, a new software add-on to their association management software, technical and whitepaper evaluators can download their papers, provide their edits and recommendations, and upload their reviewed paper to the IIAR Open Water portal. From here the authors can easily access all reviewer edits, make their final changes, and upload their finished paper via the same portal, saving hundreds of emails between staff, authors, and peer reviewers, and providing a single point of collection for all IIAR papers. Open Water will also be used by the Natural Refrigeration Foundation to accept and evaluate scholarship submissions.

Also in 2025, IIAR made its full suite of standards free to all members by making use of IIAR's association event and application software, Mosaic, and its expanded capability to allow document access. The standards were previously available through a different provider for a fee.

"Using a new function of our already paid-for software results in a significant cost savings for IIAR," said Schrift. "And by using this software that is already integrated into IIAR association management software and its member database, we can provide instant access to standards for newly joined members."

EXPANDED EVENTS IN LATIN AMERICA

In the second half of the year, IIAR made significant headway in its global standards advocacy effort, closing out 2025 with record attendance at events in the southern hemisphere.

IIAR's Chile Chapter, along with The Chilean Chamber of Refrigeration and Air Conditioning, said the organizations' twenty-eighth Seminar on Natural Refrigeration for Latin America drew over 350 attendees, the largest number of attendees in the event's history.

"This was the largest IIAR event yet in Chile," said Yesenia Rector, Vice President of Education, Outreach, and Events, adding that IIAR's Latin American chapters typically host at least one event biannually.

Despite regional differences, IIAR's Latin America seminars are global in nature, giving the industry in the hosting country the opportunity not only to network but to share viewpoints, challenges, and opportunities that are happening inside that country and around the world.

At the recent meeting in Chile, attendees from Germany, Italy, Argentina, the U.S., and Spain represented just a few of the countries in attendance. "These seminars are happening at a regional level, but they are really international in nature," said Rector.

> Using Open Water, a new software service, IIAR members will be more directly involved in the technical paper submission and peer review process.

Learning from the Past

BY KEM RUSSELL

I am sure that many of us have seen ammonia refrigeration systems that have operated for several decades, with equipment and system components functioning well past recommended operating life. This is a credit to manufacturers, installers, service technicians, and operators. Aging equipment and piping at some point will eventually require replacement. Or the system or portion of it may be decommissioned due to a business discussion.

Due to various conditions, it may become necessary to decommission a system or portions of it, which is defined in ANSI/ IIAR 8- 2020 – Decommissioning of Closed-Circuit Ammonia Refrigeration Systems as: “The permanent deactivation of a closed-circuit refrigeration system.” ANSI/IIAR 8-2020 is a helpful guide when considering decommissioning some or all of an ammonia refrigeration system. At some facilities equipment and piping may be abandoned in place for various reasons. This may occur due to the difficulty of removing the equipment and piping; the cost of removal is considered too high; or it may be abandoned in place because the unusable space taken up will not have an impact on the operation.

Whatever decommissioning is intended to be done, many factors should be considered so the work is done safely. The slow decommissioning of two separate systems at a facility in Kam loops, BC actually began on December 21, 2015, when the equipment was shut down. On May 26, 2022, during the attempt to remove equipment associated with one of the systems, an accident occurred. It resulted in one fatality, ammonia ignition, 14 persons exposed to ammonia and 3 went to the hospital, a local evacuation, extended facility business shutdown, and an environmental response to the release.

In the Technical Safety BC report of the incident, one could see that a major contributing factor to the incident was a lack of and breakdown in communication. Since this demolition occurred over several years this made the need for clear and accurate communication and documentation of what had and hadn’t been done even more challenging. This is an important factor to consider if demolition will take months or years to get done.

The misunderstanding regarding the ammonia still being in the system occurred due to changes in personnel and their assigned responsibilities as well as a miscommunication of what work had been completed. The refrigeration mechanic familiar with the system had pumped down the two systems to their respective high-pressure receivers in 2016 before his retirement.

He stated the ammonia was still in the system. The Distribution Manager also believed the ammonia was still in the system, however, the Plant Manager who had been relocated to another city thought it had been removed. It was not clearly communicated that the ammonia had not been removed from the system.

From 2016 until May 25, 2022, it was incorrectly believed that there was no ammonia in either of the two systems. The belief that there was no ammonia in either system should have been questioned when on May 25th a worker cut into an HPR pressurized ammonia line connection with a Sawzall.

After this occurred the people involved supposedly reviewed the other system for indications of ammonia. Unfortunately, those doing the demolition did not understand what they didn’t know and still held to the belief that all the ammonia had been removed, which was one of their strict criteria before removing systems or system components. They also assumed that the high-pressure receiver was empty because there was no liquid indicated in the liquid level sight glass, but they did not realize that the sight glass isolation valves were closed. They also believed that the system pressure gauges, that showed 0 psig meant the high-pressure receiver (HPR) must be empty.

These gauges did not indicate HPR pressure. It was believed that the ammonia vapor released from the first system was just residual and could be quickly purged to continue the demolition. While looking at the HPR piping of the second system it was assumed that because they saw a pipe completely open with no shut-off valve between the open end and the vessel, the vessel must have been empty. A review and understanding of whatever system piping diagrams that might have been available, as suggested in ANSI/IIAR 8-2020 Appendix B. (Informative) Example of a Decommissioning Check list could have prevented the fatality.

They should also have had help from a trained refrigeration technician or licensed contractor, but the added cost was an issue. Once it was discovered that there was ammonia pressure in the one system that should have raised a concern in the mind of those doing this work. The demolition at that point should have stopped.

A licensed refrigeration contractor should have then been involved to determine the system condition(s). ANSI/IIAR 8-2020, Chapter 5 recommends: “5.2.3.5 Do not

Aging equipment and piping at some point will eventually require replacement. Or the system or portion of it may be decommissioned due to a business discussion.

 (continued from page 17)

physically disconnect and remove system components until the components have been isolated and residual ammonia and lubrication oil have been drained from the components." Unfortunately, this was not done.

After the discovery of ammonia pressure in the first system those doing the work decided to purge what they thought was residual ammonia from the system. It is estimated that the purging process took approximately 16.5 hours and purged the entire system's ammonia operating charge, later estimated to be a maximum of 1,044 lbs.

On May 26 the removal of the second system components began. It was noticed that a valve stuck out past the support skid of the HPR so the assembly could not be laid on its side for removal from the room.

The valve was a one-inch ¼ turn ball valve with no plug or cap in the exit of the valve. The valve was in the HPR liquid supply line and had an internal extension pipe that went near the bottom of the HPR.

The valve was turned ¼ turn which fully opened the line releasing pressurized liquid ammonia directly onto the person opening the valve and quickly filling the area with a dense cloud of ammonia. The other person was able to escape through a large front bay door, but the person hit by the ammonia moved further into the building.

The dense cloud of ammonia came in contact with an ignition source and ignited. It was later estimated that 1,345 lbs. to 1,600 lbs. of ammonia had been released directly into the atmosphere. The machine room area ventilation system had previously been shut off due to the mistaken belief that all the ammonia had been removed from both systems. It was later estimated that even with a functioning ventilation system due to the large and sudden release the ignition of the ammonia would likely still have occurred.

In the post-investigation of the incident, it was discovered that the pressure relief valve on the HPR involved in this incident had at some time in the past been removed. On checking the integrity of the isolation valves associated with all connections to the HPR it was verified that all could be closed securely tight, and the vessel would hold pressure. It was estimated that the HPR held 1,600 lbs. of ammonia which was the manufacturer's recommended charge for that system.

Fortunately, the ambient conditions never reached a temperature that would have expanded the ammonia contents of the HPR to cause a failure of the vessel, a connected line, or a valve. Several factors contributed to this unfortunate incident.

The misinterpretation and poor communication of whether the ammonia had already been removed from the system was a major factor. However, following the guidelines as given in ANSI/ IIAR 8- 2020 – Decommissioning of Closed-Circuit Ammonia Refrigeration Systems would very likely have made this a non-event, saving someone's life. Don't make similar mistakes to what occurred in this incident when decommissioning a system or equipment in a system.

Whatever decommissioning is intended to be done, many factors should be considered so the work is done safely.

IIAR STANDARDS UPDATE

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

Water Contamination in an Ammonia Refrigeration System Leads to Higher Costs

In many closed-circuit ammonia refrigeration systems, water contamination can occur over a period of time and the effects of that contamination can easily go unnoticed. One thing water contamination can do is cause an aqueous ammonia solution to be formed, which then replaces anhydrous ammonia refrigerant. This problem can become continuous if it isn't resolved and will increase over time if the source is not identified. Water contamination can result in many problems for an ammonia refrigeration system. The pressure-temperature relationship can become impaired, the compressor oil may start to form organic acids, and sludge may develop from a complex chemical reaction. Other changes might include pressure drops that increase through piping and pump and evaporator performance that are adversely affected.

Sometimes, the system must be operated at a lower suction pressure in order to maintain the desired room temperatures or to handle the same processing system loads. And as the suction pressure is lowered, this increases the BHP/ton causing less compressor capacity while at the same time causing an increase in power consumption, a two-fold penalty.

So how do we identify the cause of water contamination? First we must look at how and why it is occurring. Water can gain entrance to a system in many ways. Systems which operate with the suction pressure in a vacuum are the most common source. Leaks from valve stem packings, screwed and flanged piping joints, threaded and welded pipe connections, leaking safety relief valves, pump seals, booster compressor seals, deteriorated piping, and deteriorated evaporator coils become sources of infiltration with the system operating in a vacuum.

Other sources result from inadequate evacuation procedures on startup or following the opening of the system after a maintenance service or repair. The original source may be from moisture in new vessels which were not properly drained or dried after the completion of the ASME hydrostatic test. In another scenario, for example during construction, water can enter a system as vapor through open piping or weld joints that were only tacked in place and later condensed to liquid. Condensation could have occurred in the system if air was used as the medium for the final pressure testing.

A lack of adequate purging or no purging at all can keep any non-condensables that have made it into the system from being removed, resulting in the introduction of a contaminant.

While draining oil from vessels or bleeding equipment down with a hose into a container of water prior to service or a repair in which the pressure may still be in a vacuum range could result in unwanted infiltration. An inadequate oil draining procedure could be the root cause of infiltration.

A ruptured tube or tubes in a shell-and-tube heat exchanger, such as a chiller or oil cooler, can also be a contamination source.

Performing adequate evacuation procedures on startup or following the opening of the system after a maintenance service or repair is crucial for contamination prevention.

There will be a continuous increase in water content of the ammonia in the system if steps are not taken to control the amount of infiltration. The effects of the water contamination in a system may take years to detect before the problem is truly recognized. During the non-detected time and until the water is removed and stopped, room temperatures may have been compromised from progressively deteriorated evaporator performances, suction pressures may have been lowered, more compressors may have been operating, and additional electrical energy very likely had to be consumed to meet the same requirements.

Meanwhile, the estimated amount of the water content of an ammonia system can be measured. Obtaining a sample from the system to test the water content must be done by a qualified person or persons familiar with the system using the appropriately developed and approved procedure to do so. The connection point on the system from which to take the sample should be determined to be the point where the highest water content buildup exists. The buildup of water is due to the large difference in vapor pressure between the water and the ammonia. In two-stage systems, the point will be located in vessels and evaporators serving the low side of the system. In recirculating systems, the point will be at the vessel which supplies liquid to the evaporators. In a pump system, the point will be at the pump receiver. In a gas pressure system, the point will be at the controlled pressure receiver. In flooded systems, the point will be at the evaporator and surge drum.

Once a 100 ml sample is obtained and evaporated using a graduated sampling container, the residual remaining will be a mixture of water, oil, non-volatile impurities, and approximately 30 percent ammonia (in the water residue). Once the ml residue amount is determined, the percent water present and the cost of additional operations can be estimated using specific developed charts.

Finally, a regenerator, distiller, dehydrator can be connected to remove the water in the system.

In summary, preventing water contamination in an ammonia system prevents higher energy operating costs and unnecessary maintenance service costs.

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IIAR 2026 Conference to Feature New Program, Expanded Exhibit Hours

IIAR's annual conference will deliver a tech-heavy program this year, featuring two auxiliary training and certification programs from the Refrigerating Engineers & Technician's Association, RETA, and the North American Sustainable Refrigeration Council, NASRC, as well as thirty-one sessions comprising six educational tracks and expanded exhibit hall hours.

IIAR's annual conference will deliver a tech-heavy program this year, featuring two auxiliary training and certification programs from the Refrigerating Engineers & Technician's Association, RETA, and the North American Sustainable Refrigeration Council, NASRC, as well as thirty-one sessions comprising six educational tracks and expanded exhibit hall hours.

The conference is set to take place March 15 – 18 in San Antonio, Texas, and will debut this year the first schedule format change IIAR has made since the organization began holding conferences in 1979.

"This is a significant change for us because up to now our conference has never changed the schedule format," said Yesenia Rector, IIAR's Vice President – Education, Outreach and Events. "We wanted to integrate what's happening in the exhibit hall with what's happening with our educational program."

The biggest change, said Rector, is that exhibit hall hours are intercalated with education program sessions.

The biggest change to this year's conference schedule is the full integration of exhibit hall hours with education sessions. On both Monday and Tuesday, education blocks and exhibit hall hours alternate throughout the day, with Tuesday opening in the exhibit hall instead of the business meeting. Each education block includes five to six concurrent sessions, delivering a program that allows attendees to immediately connect what they learn with solutions on the exhibit floor.

"This [change] has really improved the flow and made our conference more dynamic and more balanced because the educational program is more incorporated in the rhythm of all the events. The educational program and exhibit hall hours will work together in a more integral way, and I think attendees this year will find that the two are more complementary of each other," said Rector.

Rym Omniewski, IIAR's Conference, Meeting and Expo Coordinator said the 2026 conference will include the largest expo floor occupied so far by IIAR, at 30,300 square feet. Meanwhile, conference attendance is on track to reach nearly two thousand attendees, up from around a thousand attendees in 2022.

Rector attributed the success of IIAR's exhibit sponsorships to the continued process of feedback that IIAR asks for and gets back from its longtime partners.

"The schedule changes this year were made in direct response to feedback from long-time exhibitors who asked for stronger integration between education and the exhibition," said Rector, adding that this and other adjustments "help us fine-tune as needed to create a better experience for both attendees and exhibitors."

In addition to IIAR's educational program, 2026 will mark the second year that RETA will be offering its Certified Refrigeration Service Technician, CRST, training prior to the start of the IIAR conference. The training will be delivered over three days, Friday through Sunday. IIAR has also partnered with NASRC for the first time to offer a full day of training on CO_2 refrigeration systems on Tuesday. Both training programs require an additional registration by March 1 and have limited capacity that is filling quickly, said Rector. Attendees can register for RETA training here and NASRC training here.

Also for the second time this year, the Natural Refrigeration Foundation will host a lounge area where meeting space will be available and NRF's scholarship program and new Legacy 100 fundraising initiative will be showcased.

This dedicated space gives university and technical college students the chance to learn about the industry and meet individually with exhibitors to explore career paths, said Omniewski. Students are always welcome at the conference, but having a specific space designed for them allows them to hear directly from industry leaders, see equipment up close, and connect with potential employers—benefiting students, employers and the industry overall.

"The lounge is an area where you can come and meet with the NRF scholars, or just learn more about what NRF is doing," said Rector, adding that it is also open as a drop-in workspace that attendees can use to take a break or catch up on in-person meetings during educational program sessions.

NRF Scholarship recipients are invited to attend the full event and will have the chance to meet the IIAR executive team, the NRF Board and Trustees, and exhibitor hosts who will guide them through the expo floor and introduce them to industry partners and experienced professionals.

Before the official start of the conference, committee meetings—where much of the association's detailed work takes place—will be held on Sunday along with a dinner event to recognize committee chairs, members, board members and international partners who dedicate their time and expertise to advancing IIAR's mission.

Meanwhile, this year's social event for all members, at Pedrotti's Ranch, promises to be one of the most fun in recent years, said Rector.

"I'm really looking forward to the Monday night social event," said Rector. "It's going to be a lot of fun. We'll start with a rodeo show, there are areas with music, and the indoor-outdoor venue will have plenty of places to enjoy the festivities or find a quiet space."

The full schedule and additional conference details are available at www.iiar.org.

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Jeopardy-Style Conference Session will Highlight IIAR Standards

A new conference session format is brewing ahead of the IIAR annual conference in March according to IIAR conference planners. The session, which will take place during the event's closing day will include a lively jeopardy-style question and answer format and will focus on IIAR's standards.

"The closing forum this year is going to be really fun," said IIAR Vice President – Education, Outreach and Events, Yesenia Rector, adding that IIAR has assembled the members who lead the formation of and write the standards for the organization. She added that the three-hour conference closing session on Wednesday morning is a unique opportunity for members to hear directly from the experts on their questions.

"Throughout the year, questions [about IIAR standards] come up, and this is a big chance to get them answered all at once, by the experts," said Rector. "You'll be glad you stayed [and didn't leave early] for this session. All of our standards [subcommittee] chairs have really been working hard on this – so that members can understand how to put IIAR standards to use. It will really make you appreciate our standards and how much work goes into them and into explaining them."

IIAR's Standard's Committee Chairman, Don Faust, who will be leading the session, said one thing the group is not aiming to do is give a comprehensive review of rules and regulations. "We're hoping this is a good chance for everyone to get to know our standards in an informal way," he said. "Standards are living breathing things that are being shaped and revised constantly. Sometimes those revisions are minor and sometimes they're major, but ultimately they are reflections of things that are happening in the field."

He added that one of the most important things to understand about IIAR's standards is that they're consensus standards. "Ultimately, our standards have to represent the consensus of everyone in the industry and that starts with knowledge. The more of us who are invested in really understanding these standards and how they're used, the better."

IIAR Closing Forum

The IIAR Closing Forum is a three-hour, high-value, interactive deep dive into IIAR standards led by the people who write them. This is your opportunity to hear directly from IIAR Standards Committee leaders and subject matter experts as they walk through the intent, scope, and real-world application of each standard, and answer your questions in real time. If you have ever wondered why a requirement exists, how it is intended to be applied, or what the committee was thinking, this forum delivers clarity straight from the source.

This forum is designed as a dynamic, interactive conversation rather than a rigid, back-to-back presentation schedule. Attendees will hear concise overviews of each IIAR standard directly from Standards Committee experts, with time built in throughout the session for live polling, audience questions, discussion, and interactive activities.

Between standards discussions, the session will pause for polls, Q&A moments, and a Jeopardy-style game to keep the energy up and the learning practical.

Each segment is designed to highlight the purpose, scope, and key considerations of the standard, followed by discussion driven by attendee questions. This forum brings the conference to a strong, informative close and sends you home better equipped to apply IIAR standards with confidence.

- Hear directly from IIAR Standards Committee experts
- Get clear answers to real-world application questions
- Earn PDHs while gaining practical insight
- Participate in live polling, Q&A, and interactive games
- Leave with a better understanding of how IIAR standards are intended to work together

NRF Unveils Legacy 100 Club

IIAR's Natural Refrigeration Foundation unveiled a new fundraising effort intended to make the foundation financially secure as it funds scholarships and industry research into the next decade and beyond.

The foundation said the new Legacy 100 Fund will be built by contributions of $100,000-each to induct 100 leaders of the refrigeration industry into the Club.

The commitment can be funded by an individual, a company, or a foundation in the name of an individual. The named and honored individual will become a Legacy 100 Club member.

In an informational fact sheet about the club, NRF said "many individuals who have made a lasting impact on our industry would be honored by a gift in their name. In fact, this program is designed to specifically honor those individuals. Individuals, companies, or foundations may raise $100,000 and donate it on behalf of the individual they wish to honor."

NRF chairman, Mike McGinnis, said the Legacy 100 Club was created in recognition of the many industry leaders and innovators who have made significant contributions that have shaped or are currently shaping the natural refrigeration industry today.

"We want to recognize all the people who have helped natural refrigerants in our journey to date," said McGinnis. "The Legacy 100 Club is here to recognize our past and name the people who have shaped our industry as we know it today, from our founding until now."

Each inductee to the Legacy 100 Club will represent an impactful contribution to the advancement of natural refrigerants, said Mike Chapman, IIAR's Vice President of Operations. "This is a chance for us to collectively name and acknowledge individuals for their contributions to our industry so that everyone is aware of the history of contributions that have helped to shape what our industry has become today."

Chapman said each inductee's contributions will be showcased with a video biography posted on the NRF website along with information regarding their contributions to the natural refrigeration industry.

According to NRF, Club members may elect to receive a lifetime appointment to the NRF Board of Trustees who serve as an advisory body to the NRF Board of Directors.

The foundation said other recognition opportunities may eventually be a part of the IIAR annual conference, where the conference may showcase inductees at the annual business meeting, in signage throughout the venue and at special NRF events such as the NRF Lounge.

Club members or their funding organizations also receive satisfaction in continuing the legacy of each club member through the funding that will help sustain the advancement of natural refrigerants by creating further educational programs, scholarships and conducting necessary research on the use of natural refrigerants, according to the NRF.

IIAR's Chapman said the Legacy 100 Club is a key program for NRF, which hopes to increase the sustainability of its fundraising as an investment in the future talent of the industry through scholarships and the advancement of its science through research.

"Our intent is that we leverage these contributions to create a fund that is self-sustaining so we can maintain our research and education programs indefinitely," he said. "A big part of investing in our future is our ability to award scholarships annually to recruit skilled and talented students into the natural refrigeration industry. It's exciting that we get to do that by using these incredible stories of our past to invest in our future."

Meanwhile, said NRF's McGinnis, The Legacy 100 Club will play a vital role in supporting research.

"Research is critical to our industry, so having a way to fund these projects is so important," he said.

"This fundraising effort is critical to our organization's success. Without these research projects, we wouldn't be able to be as credible to the regulators that we're collaborating with – as we are. That's a big reason why this effort is so important."

NRF Inaugural Legacy 100 Club Members

William E. Kahlert: Contributing Foundation – The Kahlert Foundation

John Engalitcheff: Contributing Company – Baltimore Aircoil

Wilson Bradley: Contributing Company – EVAPCO

Henry A. Saye: Contributing Company – Republic Refrigeration

John L. Payne: Contributing Foundation – The Payne Family Foundation

Arthur J. Marshall: Individual – founder of AAIM Controls

Rudy Nechay: Individual – founder of Industrial Refrigeration Service

2026 IIAR Technical Papers Address AI, Heat Pumps, Data Centers

Heat pumps, real life stories from PSM coordinators and the use of AI in refrigeration and waste heat recovery for data centers are a few of the hot topics slated for discussion at IIAR's 2026 conference in San Antonio.

This year's papers will address several categories spanning safety, CO_2 optimization, heat exchangers, cold storage, ammonia charge and more. In addition, a series of panels and workshops will address many of the industry's focus areas.

Eric Smith, IIAR's vice president and technical director, said all IIAR's papers provide invaluable expertise to different specialty areas within refrigeration – with the breadth, depth, and applicability of the papers representing a valuable resource for members.

"The outpouring of work required to deliver the kind of technical program we see every year is outstanding," said Smith. "It's a testament to the depth of expertise represented by our members, and our industry-wide drive to put that knowledge to practical use."

While every paper has something valuable to offer, Smith said several papers stand out within this year's lineup for their broad appeal, given the most dominant trends and technical considerations the industry's decision makers are currently facing.

"Absorbing the Future: Innovative Waste Heat Recovery for Food and Beverage and Data Center Cooling," will look at the advantages of heat recovery for end users, particularly data centers which produce substantial waste heat as a byproduct of their on-site power generation. Absorption cooling technology, which uses heat instead of electricity to drive the cooling process, offers a sustainable and highly efficient solution at a time when data center builders are under scrutiny for their resource consumption.

The paper "A Day in the Life of a PSM Coordinator," will examine the practicalities of process safety management from several different vantage points: the coordinator, the technician and the plant manager or refrigeration manager. The format of the PSM presentation will give a clear picture of what coordinators, and a PSM program in general, need from each group.

"It's always interesting and informative to hear about the problems and advantages of boots on the ground audits from a regulatory compliance perspective," said Smith, adding that IIAR workshops will also address general safety topics this year.

One workshop, "Safe Practices for Compliant Pressure Testing Refrigerant Piping Systems," is another good place to get practical advice on compliance testing.

The workshop will provide information for contractors and end-users to ensure their refrigerant piping systems are properly pressure tested in accordance with industry codes and standards. The workshop will lay out the strategies for planning and managing the pressure testing of large piping systems in a cost-effective way while making sure personnel safety is maintained during the process of pressure testing piping systems.

Meanwhile, the idea of using AI in refrigeration will be discussed in the technical paper presentation for "Increasing Stability with Adaptive Parabolic Algorithm Control in Your Refrigeration Loop."

The paper will demonstrate the implementation of Adaptive Parabolic Algorithm Control on an ammonia refrigeration system, achieving an 80% decrease in compressor RPMs standard deviation. Energy savings and peak energy use reduction will be discussed in the context of increasing the stability of a system, allowing the site additional capabilities.

Smith said the advantages of AI in the coming years will likely surface in control systems. "Integrating that logic into control systems will help stabilize the operation of systems and will likely increase energy efficiencies and perform predictive maintenance functions."

The field of CO_2 is also expanding rapidly, said Smith, especially where CO_2 heat pumps can be applied in cooling and heating system designs.

The paper "CO_2 Heat Pumps: Main Differences with Refrigeration Systems and Real-life Examples," will look at the basic similarities and differences between a refrigeration system and a heat pump with CO_2 as refrigerant.

Even though system architectures and components are generally the same on paper, there are important practical differences, among others: control logic. There are different parameters which influence the control logic of a CO_2 refrigeration system and a heat pump.

"A heat pump system is a refrigeration system," said Smith. "But obviously, there are different parameters and limitations with the design considerations. This would be a great presentation for those who are accustomed to cooling system design and heating systems."

For those in the industry concerned with safety topics, the paper "The Vibration Failure Risk of Piping and Tubing," promises a look at the methods used for tubing vibration measurement, assessment, and failure risk. During the presentation, guidelines will be provided on how to screen operating systems as well as design guides to prevent vibration issues.

"This one is interesting because CO_2 systems operate at such high pressures that understanding how to mitigate [vibration failure risk] is crucial. Many practitioners in our industry could benefit from learning more about this issue."

While Smith stressed that IIAR attendees usually find any technical paper presentation they choose to attend to be valuable, he said the conference closing session should be an essential stop on everyone's program this year. The closing session will be a rare opportunity to learn about the details of IIAR's standards and how to use them – directly from the IIAR committees in charge of writing them.

Dayna Martinez, IIAR's education programs manager, agreed with Smith, emphasizing that this year's technical program upholds IIAR's long tradition of producing valuable technical papers.

"This program represents an intense investment of work," said Martinez. "Having all our members making contributions to continue advancing their field is an amazing thing to see. And seeing all those contributions materialize [at the conference] is huge and rewarding for everyone."

"Integrating that logic into control systems will help stabilize the operation of systems and will likely increase energy efficiencies and perform predictive maintenance functions."

TECHNICAL PAPER #5

Carbon-Dioxide System Relief Sizing

WILLIAM GREULICH, KENSINGTON CONSULTING

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ABSTRACT

Generally, safety standards for refrigeration systems require the placement of at least one overpressure protection 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,

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-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

$$udu = \; - dH$$

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^{2}s, which was returned to Table 2. The bottom panel returned a value of 42241.224 kg/m^{2}s 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.

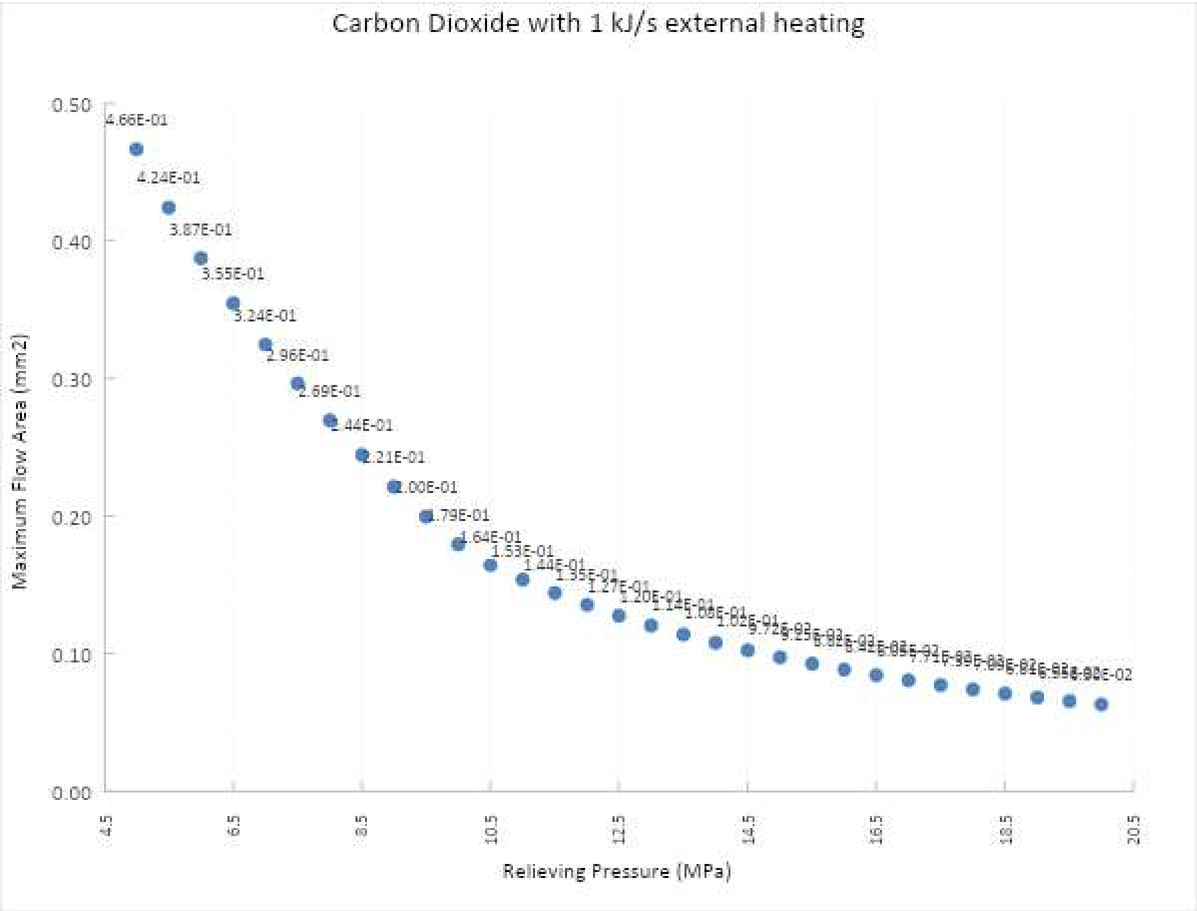
Relieving P (MPa)	Choke P (MPa)	Choke S (kJ/kg/K)	Quality x (kg/kg)
20.0	10.510	1.8064	Undefined
19.5	10.263	1.8023	Undefined
19.0	10.015	1.7981	Undefined
18.5	9.767	1.7937	Undefined
18.0	9.518	1.7892	Undefined
17.5	9.269	1.7846	Undefined
17.0	9.020	1.7798	Undefined
16.5	8.770	1.7749	Undefined
16.0	8.519	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.



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 extern 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-m^2 applied over the projected area (length x diameter)[6] and the maximum flow area of 0.135 mm^2, 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-m^2 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-m^2 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

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

Citations

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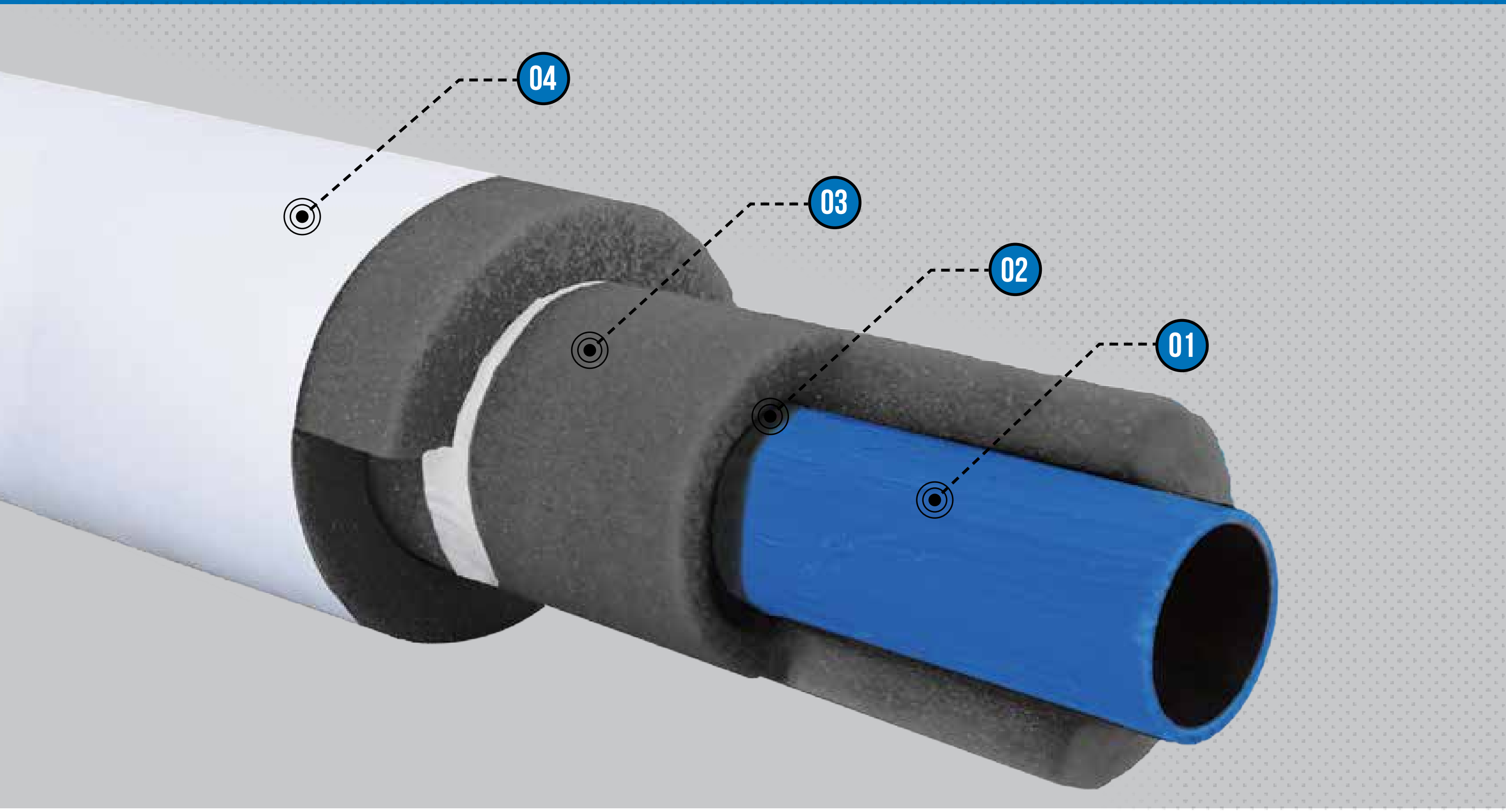

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