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CONDENSER

THE TECHNICIAN SHORTAGE

LIMITING GROWTH, CREATING CHALLENGES

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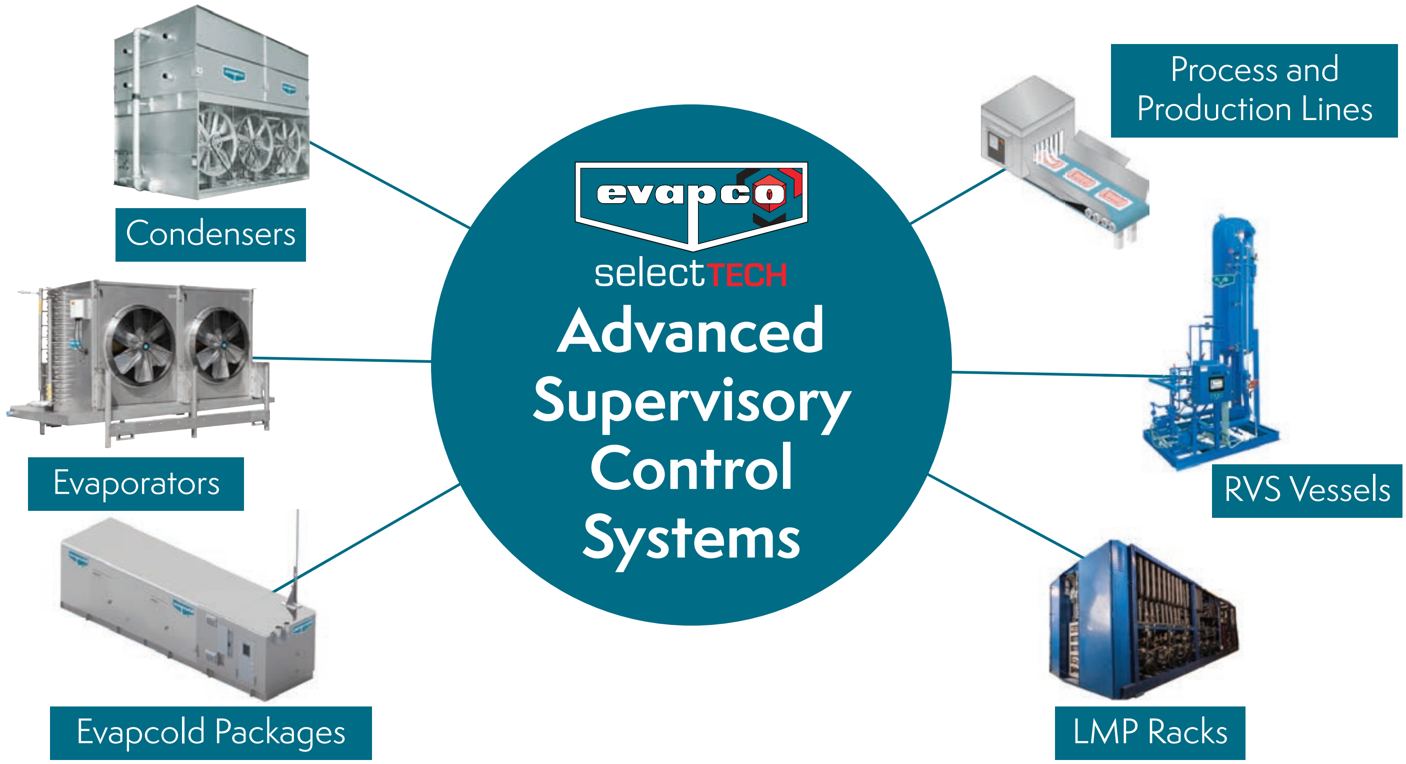

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president's MESSAGE

BY GARY SCHRIFT

The months after IIAR's annual conference are always a great time to reflect and think about the next membership year ahead. While there's always a lot going on in these last few days of summer, it's nice to pause for a moment and reflect on what it means to be an IIAR member and what new plans we have for the future.

I thought I'd take this opportunity to talk about the things I believe make this organization (and this industry) truly great.

Currently, we also create and present bi-monthly online webinars, publish peer-reviewed technical papers, and develop and update online videos providing training on basic refrigeration, service, and design.

Education: IIAR has always been focused on harnessing our collective resources and knowledge to give back to our industry. Whether that means providing refreshers on the use and implementation of our technology or laying the groundwork for the next generation of engineers, education is a top priority.

To that end, your membership organization produces and updates online courses through the Academy of Natural Refrigeration platform, providing training on the many IIAR standards and guidelines. This vast resource of non-commercialized educational materials, many also available in Spanish, significantly supports all members concerned with the safe and sustainable design, installation, and operation of ammonia and other natural refrigeration systems. These educational materials are continually being expanded to further integrate into the platform quality educational material from other affiliate organizations providing even more educational services to the world.

Currently, we also create and present bi-monthly online webinars, publish peer-reviewed technical papers, and develop and update online videos providing training on basic refrigeration, service, and design.

Scholarship: No educational effort would be complete without an effort to attract and train new talent in our industry, and IIAR does that through our Ammonia Refrigeration Foundation. Presently, scholarships are provided annually to Junior and Senior level full-time college students pursuing a degree in engineering or a related technical field leading to a career in the refrigeration industry. You may have met many of our scholarship recipients at our recent annual conference in Long Beach. I'm happy to report that this group is growing faster than ever, filling the pipeline of good candidates for employment by our members.

Standards: The formation of the guidelines that drive the growth of our industry has always been the core of IIAR's mission. As a standards organization, the material we produce proves to code bodies, governmental departments, and end-users that natural refrigerants can be applied safely and managed efficiently for refrigeration and comfort cooling applications. We already know that natural refrigerants are safe for the environment. Our standards ensure the safe use of natural refrigerants by dramatically reducing the chance of an accidental release and dramatically increasing the safety of personnel and neighbors of the facility.

Research: To inform and support standards creation, we need to first understand what we want to describe in our standards, and that's where research comes in. IIAR research projects are coordinated by the Research Committee and IIAR staff, and funded by the Foundation. These projects result in the development of products like guidelines for Mechanical Insulation Installation, or three computer programs available in conjunction with the IIAR Ammonia Piping Handbook. These reflect significant changes to the pipe sizing chapter, wet suction riser selection, and economic considerations.

Meanwhile, proposed research projects will result in a better understanding of ammonia dispersion and detection in refrigerated space and engine rooms, and best piping practices to avoid hydraulic shock based on CFD modeling and comparisons to actual past events.

Advocacy: Of course, the final step in standards creation is to take what we've produced as an organization and get it applied in real life. That's where our advocacy effort comes in.

Every IIAR program and initiative is made possible by your membership, and additionally, by your leadership as a volunteer.

I'd like to use this space this month to remind everyone to be sure to renew their IIAR membership and find a new way to get involved. It's the best way to make sure you connect with this ever-growing community of friends and colleagues who are passionate about natural refrigerants.

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chairman's MESSAGE

BY DAVE MALINAUSKAS

As we wrap up a busy, and hopefully restful, summer, I want to take this opportunity to welcome everyone – new and renewing members alike – to IIAR. I know I'm well into my term as your IIAR Chairman, but this welcome, and re-welcome, is in order because our membership is always growing, and your staff is busier than ever supporting that growth by completing the products and projects that move us closer to our strategic vision.

It's always the hard work and contributions of IIAR's membership that moves us forward, so it's appropriate to take a minute and extend special thanks and appreciation to all who contributed their time and financial support to this year's recent conference in Long Beach.

If you didn't already realize that we're in the midst of IIAR membership renewal season, the success of that conference is a great reminder of how essential IIAR membership is to the leadership of our industry.

Resolving some of the most complex scenarios we face in the coming years will depend on the ability of IIAR's membership to come together and continue to develop the resources and communicate the potential of new technologies. That's something you can do now by finding ways to get, or stay, involved in the many activities of our organization.

There are many challenges – and opportunities – facing our business environment. This year we've again focused on the regulatory landscape and examined the technology and best practices we'll need to meet growing demand from so many new and traditional sectors.

Resolving some of the most complex scenarios we face in the coming years will depend on the ability of IIAR's membership to come together and continue to develop the resources and communicate the potential of new technologies.

Meanwhile, as you'll read about in this issue of the Condenser, we're working on IIAR's first hydrocarbon standard, a natural extension of our mission to offer safe practice standards as the refrigeration industry turns to low global-warming-potential solutions.

I'm proud of IIAR's significant output of all of our new and revised standards. These efforts further solidify our organization as the authority on all-natural refrigerants, and they also lay the groundwork for a host of other member benefits and services like educational guidelines and classes offered through the Academy of Natural Refrigerants.

IIAR's greatest asset is the vibrancy and engagement of its various committees. It has been encouraging to experience first-hand how well our committees are attended by volunteers, how active our membership is in advancing and supporting the work of IIAR's committees, and how dedicated our staff has been in developing new services.

All of these achievements are the result of everyone's hard work. I would like to thank you all for volunteering your time and actively committing to IIAR– your effort is continuing to pay off.

I'd also like to take this opportunity to call not only for your renewed membership but also for your increased participation and leadership in IIAR's committees and the development of conference technical papers. Whether you get involved as a committee member or tech paper author, or in any other way, your involvement is what moves us forward.

We're continuing to grow as a resource for the educational and training materials that make our industry safe and enable the use of new natural refrigeration technologies.

Meanwhile, our publications are second to none, addressing new trends and introducing new technologies, and you, as an IIAR member have the opportunity to contribute to them directly.

You also have an opportunity, as a member, to expand your interaction with your peers, and influence the policies, codes, and standards that shape the way we do business. Our committees span all of these areas and beyond, and they all depend on your help and support in some form.

However you decide to get involved this year, I'm hoping you'll see this IIAR membership renewal season a little differently, as a chance to dive into the work of your organization. We're growing like never before, and I'm looking forward to working with you all in the year ahead.

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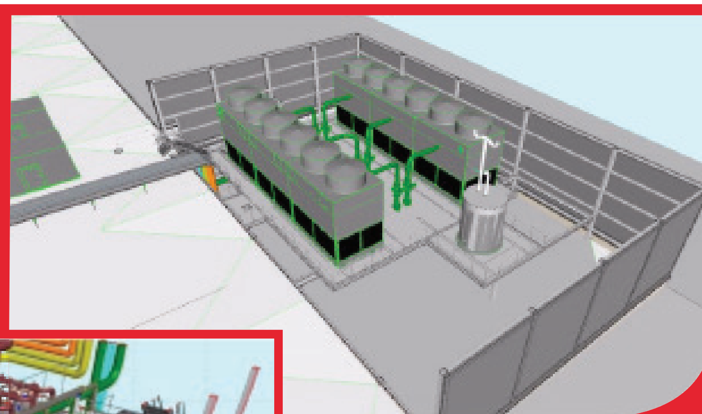

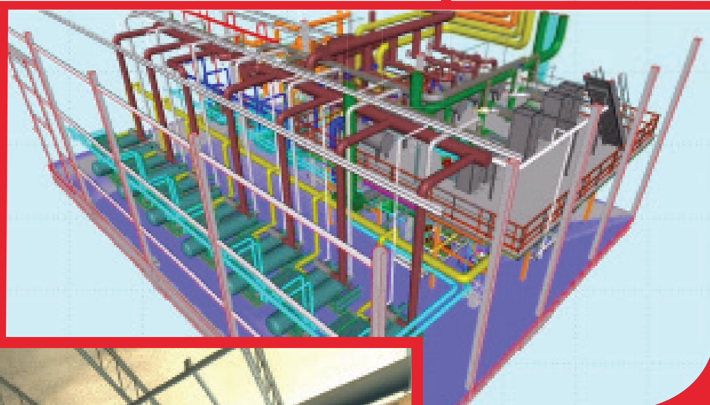

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COVER STORY

THE TECHNICIAN SHORTAGE

LIMITING GROWTH, CREATING CHALLENGES

The refrigeration industry has been facing a shortage of skilled workers for years, and the problem continues to grow, creating significant challenges, disrupting essential operations, and limiting growth.

"At a high level, the workforce shortage creates a bottleneck that threatens the industry's ability to meet regulatory timelines," said Danielle Wright, executive director of the North American Sustainable Refrigeration Council.

The technician shortage is the biggest limiting factor to the HFC phasedown. "Federal and state regulations are driving the transition away from HFC refrigerants, but there are simply not enough technicians to enable this change, let alone service all the existing systems. Ultimately, this puts the future of food retail at risk," Wright said.

That is one of the reasons the North American Sustainable Refrigeration Council conducted its Workforce Development Assessment Report. "We wanted to understand the drivers of the shortage and develop data-driven, effective solutions to build a sustainable refrigeration workforce," Wright explained.

QUANTIFYING THE SHORTAGE

While data from the U.S. Bureau of Labor Statistics projects 40,100 HVACR job openings each year between 2021-2031, it doesn't specify where or how big the shortage is for refrigeration jobs specifically. "A big part of the problem is that we don't have comprehensive data on the size or location of the workforce gap that is specific to the refrigeration sector," Wright said. "This lack of data makes it hard for the industry to respond proactively and bridge the gap."

What's more, the existing shortage may be causing people to leave due to the negative-reinforcing the technician burnout loop. "This job already requires long grueling hours, which are only exacerbated by the shortage of new technicians entering the field and the number that are exiting or retiring out, creating even more unsustainable schedules that lead to further technician shortages," Wright said.

Simply put, not enough young people are coming into the industry as Baby Boomers retire. "We were a grey industry 10 years ago and it is even greyer now," said Don Faust, training manager for Johnson Controls.

Currently, 40% of the 12 million people in the entire skilled trades workforce are over the age of 45, with nearly half of those workers over the age of 55, and less than 9% of workers aged 19-24 are entering the trades, according to an analysis by PeopleReady Skilled Trades.

Limited awareness of opportunities in the trades, including refrigeration, is contributing to the shortage. In many ways, refrigeration technicians fulfill an unseen but essential job that most people don't know exists. Darrow Soares, Professor Emeritus, Air Conditioning and Refrigeration, Mt. San Antonio College, said exposure must begin earlier. "Commercial refrigeration is not a career that young people consider

unless one of their parents works in the industry," he said. "Others, including high school and junior high counselors, associate the career with what they have been exposed to—their domestic kitchen refrigerator."

Unfortunately, parents and counselors cannot picture a successful and lucrative career with that image in mind, Soares said. To start changing students' and parents' thinking, the industry needs to reach out to both groups while students are young. "High school career fairs are too late," he said.

Wright said a lack of awareness of refrigeration can even occur in tech schools. "Even if they are enrolled in an HVACR program, there's little emphasis on the 'R' side," she said. "This can be addressed by providing more refrigeration training for the trainers, more resources and equipment to support learning and more opportunities for students to connect with the refrigeration industry. Overall, we need to build more exposure to the refrigeration career at every step of the career pathway."

UNDERSTANDING THE PROS AND CONS

Touting the benefits of working as a refrigeration technician could help attract new entrants. Wright said NASRC's survey found that techs have a high level of overall job satisfaction. "Over 85 percent of respondents to our survey said they were satisfied or very satisfied with their career," she said. "Benefits include job security, the fact that it's recession-proof, low to no educational debt, and geographic flexibility. Most importantly, this job offers very competitive pay with high growth potential."

Soares said physically fit students, who have a strong sense of responsibility, are curious about technology, and have a willingness to constantly learn will always be successful as refrigeration technicians. He tells students and anyone else considering the career that they will have a consistent job that pays a living wage for the rest of their lives.

"We will always have to provide food and commercial refrigeration makes it available. Plus, it is not easily outsourced through technology," Soares said. "It takes boots on the ground to install and commission the equipment."

Troubleshooting mechanical issues can begin remotely, but it takes experienced technicians to show up and put their hands on the equipment, listen to and watch the operation, and physically do the work to restore or maintain the operation, Soares said.

However, technicians can face long and unpredictable hours. "This is a job that can require being on call nights, weekends, and holidays. There's seasonal inconsistency, long drive times, and its physically challenging work," Wright said.

Plus, mechanical failures can be more catastrophic than those in comfort cooling. "Not everyone can handle working under high stress, high-pressure situations, where the clock is ticking to fix an issue with a system that could lead to potentially millions of dollars' worth of revenue loss due to food spoilage," Wright said.

TAKING ACTION

Solving the technician shortage requires an all-hands-on-deck approach. "There's something everyone in this industry can do to contribute," Wright said, adding that many companies are already taking action.

Faust said manufacturers and industry associations, including IIAR, have a critical role to play in making training resources available so people can learn more about the field, different disciplines and needs, and how to be successful. "That comes right down to maximizing online training, both from the IIAR training as well as others," he said. "You can't count on just having an apprentice follow someone around for a long time to pick it up."

Online and virtual training could make training more accessible. "Attending classes where people have to fly across the country and spend a week and a half away from work is difficult," Faust said. "Making training accessible and having someone take an online course half an hour a day and sip it in rather than getting a fire hose will help people get more familiar with the industry."

Companies should also consider reaching out to their local community college refrigeration program, adult school, or regional occupational program, Soares said. "Begin with administration and make your intentions known. Insist on joining their advisory committee," he said. "Come into the advisory with a clear ask— teach these concepts—and then be ready to offer resources in the form of curriculum assistance, adjunct faculty, access to equipment, and employment."

Even still, Wright said this isn't a problem that can be solved by any one individual company. "We need a coordinate effort across the industry that simultaneously addresses technician recruitment, training, and retention gaps."

NASRC has formed a workforce development program to provide a platform for coordinated action. "We aren't trying to reinvent the wheel, but instead amplify and align existing efforts while filling any gaps," she said.

The concept is to take the recommendations from the report and implement them at a regional level since many are too large to tackle all at once at a national level. "Initially, we are taking a local, bite-sized approach, testing out solutions to see what works and then scaling up from there," Wright said.

A good example is the Natural Refrigerant Training Summit NASRC hosted with Southern California Edison earlier this year. The event brought together refrigeration trainers from 12 different organizations, over 250 technicians, and almost 100 students and faculty from local HVACR programs. "For the first time, we were able to combine workforce development, through robust technical training in CO_2 and propane technologies, with student recruiting and building relationships with local school faculty," Wright said.

Initiatives to attract more women and minorities, new outreach programs, and scholarships could also help bring new entrants to the industry. With regulatory requirements increasing and the demand for refrigeration services expected to continue to grow, the refrigeration industry needs to find a way to appeal to workers.

"This career is for anyone who wants to make a direct impact, who would rather be working with their hands than behind a desk, who likes to solve interesting problems and learn new things, who value financial independence, and who wants to work with good people," Wright said.

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Upcoming IIAR Conference Features Significant Changes

The 2024 IIAR Natural Refrigeration Conference & Heavy Equipment Expo, March 24-27, in Orlando, will bring several significant changes from previous years, including an updated schedule and an exclusive Natural Refrigeration Foundation Fun Day.

"Ultimately our post-conference survey received many positive improvement recommendations with most people not wanting a longer conference, but many people wanting new things added," said Gary Schrift, president of IIAR. "The only way to accommodate new programs being added was to remove some that we felt were not essential and to re-order timing of things to make a more efficient use of the days we have."

COMMITTEE MEETINGS AND RECEPTIONS

Activities will kick off on Saturday, March 23, which will feature IIAR's board meeting. Most committee meetings will take place Saturday afternoon instead of Sunday. "The committee meetings are the heart and soul of where the work gets done. By having almost all of the committee meetings taking place on Saturday, we can get a lot of the focused work done," said John Flynn, chairman of IIAR's education committee and director of business development for General Refrigeration.

Flynn added that any committee meetings that don't take place on Saturday will be held Tuesday morning. "A lot of volunteer labor has to take place at the committee level," he said.

On Saturday night, the association will feature the first IIAR VIP Dinner/Reception. "Although the name may sound familiar, this event on Saturday night is to welcome all IIAR Board, Committee Chairs, and Committee Members," said Yesenia Rector, IIAR's meetings and international program director. "The objective is to thank our committee members and foster connections between IIAR committee members, including international committee members, and the board of directors."

NRF FUNDAY

Sunday, March 24, will feature the NRF Fun Day, which will have three tournaments—golf, pickleball, and cornhole—all starting in the morning. "We've had the golf tournament for decades, but only a limited number of people get to participate. By adding pickleball and cornhole, we anticipate a broader group of players and a bigger audience to watch the games," Flynn said. "It will be a welcome change for those that want to participate or watch their friends participate."

The goal is to raise awareness and donations for the NRF and its mission. "As everyone is enjoying the events, I hope that they will also become more involved with the NRF and help us to

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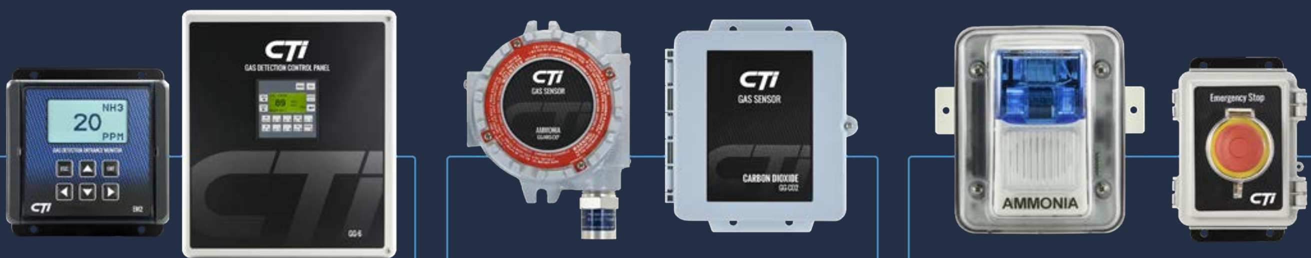

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www.ctigas.com | sales@ctigas.com | 866-394-5861 promote natural refrigerants and inspire a younger generation to pursue careers and support our industry's effort to expand the use of natural refrigerants," Flynn said. "These days everyone, and especially students, appreciate that natural refrigerants are environmentally friendly, energy efficient, don't deplete the ozone layer and have ultra-low global warming potential."

Flynn noted that this year the NRF Scholarship had a record number of applicants, including nearly half from schools that had not previously applied for the NRF Scholarship. "This year, the NRF board approved the expansion of the scholarships to eight new candidates. We hope that by expanding the quantity and quality of NRF scholarship, we will be able to attract the next generation of natural refrigerant advocates who will serve as champions for our industry," he said.

The three tournaments will all end around the same time. "Then we will have an NRF Reception to announce the winners of all the tournaments, talk to people about the NRF, and thank our sponsors for the tournaments and donors throughout the year," Schrift said, adding that this reception takes the place of the past Saturday evening NRF VIP reception. "Then, early Sunday evening, the IIAR kickoff receptions begin with Women in Refrigeration, First Timers, and the Chairman's receptions."

Flynn said having the receptions on Sunday is important. "We want to make sure we get a lot of board members and industry veterans there so the people who are coming for the first time get to know people. It is nice to meet the new attendees early, and when you see them on the floor you can ask them how it is going," he said.

The Women in Natural Refrigeration event is designed to help encourage diversity in the organization. "It is a way for women and other underrepresented groups to find a network of people that can support them in this industry," Flynn said.

The Sunday program is capped off by the Annual Chairman's Reception, which Flynn said is an excellent place for those in the industry to connect. "IIAR is the people. There is a lot of camaraderie in the industry, whether you are competitors or collaborators, when you get to an event like that, everyone is part of the same team," Flynn said.

In the past, Sunday featured IIAR's Sunday Educational program, which the association will not hold in 2024. "So, from early morning through late afternoon, Sunday will be wide open hoping that many participate in our three tournaments and the final receptions," Schrift said.

STUDENT DAY

IIAR is working to increase interest in the industry, and Wednesday will feature a Student Day. "Students are always free and can walk the exhibit hall at any time, but we are having a program targeted to the young engineers," Flynn said, adding that students will be paired with someone in the industry and will visit exhibitors' booths for discussions about the industry and hands-on exposure to the components and equipment used in industrial refrigeration.

"We are reaching out to top Florida engineering schools that might want their students to attend the Orlando event. There is also an effort to reach out to the historically black colleges and universities to develop more diversity in the organization," Flynn said.

Recipients of the NRF Scholarships are also invited to attend the full event. "During the conference, these scholars will have a front-row seat as they meet with the IIAR executive team, the NRF Board and Trustees, and their exhibitor hosts who will guide each of them through the showroom floor, meeting with exhibitors and other industry veterans as they see the equipment that is used in industrial refrigeration," Flynn said. "These are incredible young people who are inspired by the mission of natural refrigeration to help the climate."

EXCEPTIONAL EDUCATION

The event will continue to feature educational seminars, talks, and presentations of papers. "The education will be robust, as always. We'll be focusing on the latest ammonia and CO_2 technologies. There is a lot on heat pumps, IIAR-sponsored research, and the importance of developing and documenting the PHA programs," Flynn said.

There will also be sessions in Spanish, and IIAR is continuing to develop resources for Spanish-speaking members. "In our commitment to providing the educational tools and materials to support our membership, IIAR has now translated all three of our Training Video Series to Spanish. This is a major accomplishment as we look to expand our outreach to Spanish-speaking communities, not only within North America but also to South and Central America," Flynn said.

For the first time, the meeting will feature a RETA CRST certification training class. It will occur Friday, Saturday, and Sunday with testing on Monday.

IIAR has converted the Closing Seminar into a structured Town Hall event where participants will be examining the current state of our industry. "I expect that our members will discuss changes affecting our industry, such as the AIM Act and the EPA's refrigerant regulations, as well as opportunities that may open up for refrigeration professionals and natural refrigerants," Flynn said.

SPONSORSHIP OPPORTUNITIES

Sponsorships sales will occur online, via the our Conference Sponsorship Platform. Sponsors can select their sponsorship, sign the sponsorship contract, and view and pay their invoice online. "General Conference Sponsorships are ongoing, and NRF sponsorships will be available for purchase the week of August 24th," Rector said. "From now on, we will include NRF sponsors as well as the General Conference Sponsors in the VIP Priority Group for exhibit space and sponsorships signups."

Like sponsorships, exhibit space sales will occur online, where exhibitors will complete the Exhibit Space Application, and then confirm their choice online, sign the contract, and view/pay their invoice online.

Technomercials are now Product Showcase Presentations. "We will have more opportunities than ever for exhibitors to purchase presentation spots," Rector said. "These will be sold as part of the exhibit space sales process."

Assessing and Mitigating Risk

Managing risk is an important part of any business, but especially for those that work with refrigerants, which can create a safety hazard if they aren't handled properly. However, the best ways to manage and estimate risk aren't always clear cut.

"I think known, high-level risk is assessed regularly and most often effectively. The risk I see as being under-evaluated are small mechanical changes, as well as organizational change," said Drew Hart, senior manager of environmental health and safety for E. & J. Gallo Winery.

Currently, there is a wide range in the ways the industry addresses risk mitigation. "For companies with established process safety culture, I think this is done at a high level," he said. "New or non-existent management systems dramatically reduce the efficacy of risk mitigation efforts."

Harold Streicher, Principal Innovation Officer for Hansen Technologies Inc., said a lot of ambiguity surrounding risks assessment remains. "In an effort to better understand how organizations identify and rank risk, it has revealed a very grey area around how they assign a (monetary) value to risk. and this is certainly worth understanding," he said.

Streicher added that by building on the traditional PHA methodology for assessing the risk matrix/outcome, those in the industry can now conduct a "Financial Hazard Analysis (FHA)" to measure total risk exposure versus risk mitigation value and costs. "This will provide a simple risk over investment ratio to help rank and clarify the value of risk to financial decision makers," he said.

> "I think known, high-level risk is assessed regularly and most often effectively. The risk I see as being under-evaluated are small mechanical changes, as well as organizational change."
>
> **Drew Hart, senior manager of environmental health and safety for E. & J. Gallo Winery.**

ASSESSING RISK

Understanding risk usually involves asking three questions: what can go wrong, how likely is it and what are the impacts. The two primary ways that risk is assessed in the ammonia refrigeration industry is by completing a Process Hazard Analysis (PHA) and by performing a Hazard Assessment and Offsite Consequence Analysis (OCA), said Peter Thomas, president of Resource Compliance Inc. He added that PHA, mechanical integrity and other Process Safety Management recommendations can help companies determine the best way to mitigate risk.

"Often recommendations are the result of an unacceptable level of risk. Therefore, measuring the number of completed recommendations is one way to assess risk mitigation," Thomas said.

When performing a PHA, risk is typically evaluated by considering both the severity or likelihood of a scenario occurrence. So, risk increases as either the severity or likelihood increases, Thomas explained.

PSM, an Occupational Safety and Health Administration program intended to protect workers, and the Environmental Protection Agency's Risk Management Program, which is intended to protect the environment and the community, both list safety-related elements companies have to complete. "You have to do a process hazardous analysis to look at things that could cause harm and have a plan around mitigating those risks," Streicher said. "In our arena, they do what-if analysis to say what could happen if and they'll say how likely is that to happen. Then you can say, 'How can you mitigate the risk?'"

Thomas said some facilities that operate systems with less than 10,000 pounds of ammonia and are not subject to RMP/PSM have voluntarily implemented mechanical integrity and training programs to mitigate risk. "This serves our industry well by reducing accidental releases," he said.

The formal structure of PSM and RMP regulations help to ensure there isn't a drop in the program efficacy, Hart said. "As an end user, much work has to be done to build the program past the skeleton of the regulation," he explained. "That is precisely why companies that lack the institutional knowledge will struggle to implement effective management systems."

Hart said a glaring deficiency in the regulations he sees is that there is no mention of control plan or evaluation of process health past compliance audits every three years. "Companies must develop a KPI platform to give the operation day-to-day confidence in process health," he said.

When going beyond PSM and RMP, Hart said he appreciated the addition of IIAR standard 9 to address aging systems. "I think that was a big gap. In the future I would like to see more resources dedicated to General Duty management system best practices."

EVALUATING NEAR MISSES

Near misses and data analysis should drive the vast majority of long-range planning, according to Hart. "We need to make the denominator as high as possible in terms of events analyzed to be highly confident in our data. That data then becomes the basis for capital justification," he said. "Near misses are our gift to help fix deficiencies before they negatively impact a team member."

Thomas agreed that applying the lessons learned from previous incidents is a great way to reduce the likelihood of a recurrence.

Peter Jordan, an active member of IIAR's many committees and the principal engineer at MBD Risk Management Services, published a technical paper for the 2020 IIAR Annual Meeting titled "Case History: A Study of Incidents in the Ammonia Refrigeration Industry." The paper summarized the incident information described in RMPs submitted between 1994 and 2004, incident reports posted on the Chemical Safety Board's website, and information gathered from web pages, newspaper articles, blogs, and other scientific research.

GAINING ADDITIONAL INSIGHTS

While the industry is familiar with the PHA risk assessment tool, Streicher said the cost of the consequence isn't fully understood. "PSM is about risk reduction. PHA is risk assessment, and now we're talking about risk valuation," Streicher said. What is that risk that we're absorbing or not absorbing and the value of that vs the cost of mitigation?"

Streicher is currently putting a model together to assign a monetary value for risks associated with relief valve events and mitigation efforts. "I tried to put a comprehensive range of costs to those risks. For example, consider the small, but typical fine for a lack of fall protection is $15,625. Then, jump down to if it is a PRV (pressure relief valve) event that can shut down a plant for a day, that could be as high as $1 million in the loss of product and loss of productivity," he said.

If there is a catastrophic event that shuts a facility down for 10 days or more, it could result in $10 million dollars or more in losses, Streicher added. "The exercise of thinking through what it could mean to employees and the business is important," he explained. "Risk Valuation is not about the probability of an accident but the possibility of an accident." This understanding of Risk Valuation can become an important way to communicate and justify investments in process safety improvements to those who are responsible for financial decisions.

Striecher said he has also drawn on OSHA tools, including https://www.osha.gov/safetypays/estimator, when creating his model.

LOOKING IN

People outside of the industry, such as insurance companies, look at risk at a much higher level and tend to be very black and white, Hart said. "PSM/RMP are performance-based regulations for a reason," he explained. "A good example is flammables. Insurance companies largely look at water miscible flammable liquids the same way OSHA does—by flashpoint and volume of the mixture. Temperature of the mass of liquid is a major variable for vapor creation but is not part of the analysis."

Jordan added that insurance companies and government agencies tend to rely on IIAR standards in assessing risk. "They will often view compliance with minimum standards and a measuring stick for risk," he said.

"We need to make the denominator as high as possible in terms of events analyzed to be highly confident in our data. That data then becomes the basis for capital justification," he said. "Near misses are our gift to help fix deficiencies before they negatively impact a team member."

Drew Hart, senior manager of environmental health and safety for E. & J. Gallo Winery.

OSHA Announces New Emphasis Program Targeting Warehouses and Distribution Centers

iiar government RELATIONS

BY LOWELL RANDEL, IIAR GOVERNMENT RELATIONS DIRECTOR

On July 13th, the U.S. Department of Labor's Occupational Safety and Health Administration (OSHA) announced a new national emphasis program (NEP) targeting workplace hazards in warehouses, processing facilities distribution centers, and high-risk retail establishments. While the NEP is not focused on ammonia refrigeration systems like the NEP on chemical facilities, many facilities using natural refrigerants will be subject to the new emphasis program. OSHA cited significant growth in the sector over the last ten years, coupled with high injury and illness rates to justify the new emphasis program. OSHA asserts that data from the Bureau of Labor Statistics shows that injury and illness rates for these types of establishments are "significantly higher" than rates for general industry.

The NEP is currently scheduled to run for three years, but similar to the NEP on chemical facilities, could be renewed after the initial three-year period. As with other National Emphasis Programs, State Plan states must adopt a program that is identical or is at least as effective, as the NEP. Under the new emphasis program, OSHA will conduct comprehensive safety inspections focused on hazards related to powered industrial vehicle operations, material handling, and storage, walking and working surfaces, means of egress, and fire protection. The program will also include inspections of retail establishments with high injury rates with a focus on storage and loading areas. It is important to note that OSHA can expand an inspection's scope when evidence shows that violations may exist in other areas of the establishment. That could bring additional inspection attention to refrigeration systems, should inspectors find evidence of potential violations.

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In addition, OSHA will assess heat and ergonomic hazards under the emphasis program, and health inspections may be conducted if OSHA determines these hazards are present. The Biden Administration has recently placed a high priority on addressing heat-related hazards. On July 27th, the Department of Labor announced that OSHA has issued a heat hazard alert to remind employers of their obligation to protect workers against heat illness or injury in outdoor and indoor workplaces. The department also announced that OSHA will intensify its enforcement where workers are exposed to heat hazards, with increased inspections in high-risk industries like construction and agriculture. These actions will fully implement the agency's National Emphasis Program for Outdoor and Indoor Heat-Related Hazards, announced in April 2022, to focus enforcement efforts in geographic areas and industries with the most vulnerable workers. In addition, the government has launched a new website called "heat.gov", which identifies where current heat alerts are taking place, and information on how to best mitigate and prevent heat-related illness, stresses, and other negative effects.

The OSHA directive for the NEP clarifies that worker exposure to ergonomic hazards must also be assessed during a review of the employer's injury and illness logs, during worker interviews, and the establishment walkthrough. When exposures to ergonomic hazards are occurring, the inspection scope shall be expanded, and a health inspection shall be opened.

Inspected establishments will be chosen from two lists. One list includes

establishments with industry codes covered under this emphasis program. The second consists of a limited number of retail establishments with the highest rates of injuries and illnesses resulting in days away, restricted duty, or job transfer.

Below is a listing of NAICS codes for industries covered by the NEP:

NAICS CODES ESTABLISHMENTS

- 491110 Postal Service (Processing & Distribution Centers only)
- 492110 Couriers and Express Delivery Services
- 492210 Local Messengers and Local Delivery
- 493110 General Warehousing and Storage
- 493120 Refrigerated Warehousing and Storage
- 493130 Farm Product Warehousing and Storage
- 493190 Other Warehousing and Storage

The following NAICS codes identify the types of retail establishments subject to the NEP:

NAICS CODES HIGH INJURY RATE RETAIL ESTABLISHMENTS

- 444110 Home Centers
- 444130 Hardware Stores
- 444190 Other Building Material Dealers
- 445110 Supermarkets and other grocery stores
- 452311 Warehouse Clubs and Supercenters

Inspections under the NEP, except for high injury rate retail establishments, will be comprehensive safety inspections and will focus on workplace hazards common to those industries, including powered industrial vehicle operations, material handling/storage, walking-working surfaces, means of egress, and fire protection. Heat and ergonomic hazards must be considered during all inspections covered by this NEP and a health inspection shall be conducted if OSHA learns that heat and/or ergonomic hazards are present.

Inspections of high-risk retail establishments covered by the NEP will focus on the loading and storage areas, but OSHA may expand the scope of the partial inspection when there is evidence (e.g., injuries or illnesses recorded in both OSHA forms 300 and 301, employee statements, or "plain view" observations) that violative conditions may be found in other areas of that establishment.

Inspections initiated by OSHA based upon fatalities/catastrophes, complaints, or referrals related to establishments in the NAICS codes covered under this NEP will be expanded to address the workplace hazards targeted by the new NEP. It is also important to note that inspections conducted under the new NEP may be combined with other programmed and unprogrammed inspections. As a result, IIAR members undergoing programmed inspections under the NEP on Chemical Facilities or other types of OSHA inspections may see those inspections expanded to include the scope of the new NEP.

In preparation for potential inspections under the new NEP, IIAR members with facilities covered by the NAICS codes listed in the NEP are encouraged to review their policies and operations with a particular focus on powered industrial vehicles, material handling/storage, walking-working surfaces, means of egress, fire protection, heat hazards, and ergonomics.

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Understanding

Have you ever thought about your understanding of the equipment and tools we use as well as the entire refrigeration system(s)? Many times, or maybe all of the time we assume we or someone else understands until something happens. This may be like the definition of confidence I have heard, which is "That feeling you get just before you understand the situation."

I have had understanding challenges myself and with others in refrigeration systems and the tools we sometimes use. I recently had an experience, although not in the refrigeration field, that illustrates the importance of understanding. A little over a month ago I went hiking to the top of a local peak that tops out at 6,473 feet, climbing about 3,200 feet from the trailhead. The weather was not quite what I was hoping for. It was cool, which was great, but also cloudy with off-and-on sprinkles. Reluctantly I put on my rain shell, which is very bright orange.

I topped out in about 2 hours and the fantastic views I was hoping for were invisible. Clouds surrounded the peak and the trees just below the peak were wrapped in waving foggy layers. It was kind of neat but certainly not what I was hoping for. There was a little breeze on the exposed peak and because I had my rain shell on I was damp from sweating so instead of taking a break I decided to hike back down about a mile to a saddle area in the forest that I knew would be a good stopping place, since I had passed through there on the way up.

As I started down I heard voices on the trail somewhere below me. I figured I would run into whoever it was, but I got to the saddle area, which is a somewhat open area without seeing or hearing anyone. I grabbed a small handful of nuts and drank some water and while doing this I heard the voices again this time up a ridge trail instead of on the branch trail I was going to take down. Not wanting to intrude on someone's "natural experience" I quickly packed up and headed down the branch trail.

I was just getting out of the open and into the forest when my bright orange rain shell gave me away. From up above me on the ridge trail a lady yelled "Hey! Can you help us? We're somewhat lost." This goes along with the definition of confidence. You think you know where you are until you suddenly realize you don't know where you are.

I was just getting out of the open and into the forest when my bright orange rain shell gave me away. From up above me on the ridge trail a lady yelled "Hey! Can you help us? We're somewhat lost." This goes along with the definition of confidence. You think you know where you are until you suddenly realize you don't know where you are.

I yelled back up for them to hike down to the saddle and I would meet them there. There were two ladies and they had hiked up from the north side of the mountain. I came up from the south side. They had a mapping program on their cell phone that was working and did show exactly where they were. It also showed their track, indicating they had hiked past the peak and continued for over a mile before they realized they didn't know where they were going. It is extremely important to know how your device(s) works and what it is telling you before you put yourself someplace where the information is very important. A similar principle applies to refrigeration and almost everything else in life.

They wanted me to explain how they could get back on the trail leading down the northside. This correlates with experiences we all probably have had when we explain something to someone who doesn't have much of a clue as to what you are talking about.

The ladies had blamed their confusion on the foggy and cloudy conditions. However, I thought in my mind that as long as your GPS device is getting a good satellite signal you can follow a trail in poor conditions, even in the dark where you can't see much except within the cone of your headlamp. Been there, done that. Thinking of this and how these ladies had already not been able to follow the directions on their device and I figured if I tried to tell them how to get back to the northside trail which was about 1.5 miles from where they were, they would very likely get lost, again.

I said to the ladies, "You know it would be a lot easier instead of hiking a mile up and over the peak if you just followed me down this trail to my car and I'll drive you around to the northside to your car." They happily agreed.

We must understand how to properly use the tools and equipment we rely on no matter what we are doing. The same applies to understanding the operation of refrigeration systems and all of their components.

There are several reasons we may be challenged in our understanding. Some of those are:

- **Language.** I have worked with not only installers but refrigeration operators where English is a second language. Sometimes a very distant second language. More than once I have talked to someone where we had a "a failure to communicate". They may make head movements or verbal sounds indicating they understand, but they actually don't. In cases where this has happened, and I realized it (that's a key point too) I have used a sketch or drawing to illustrate what I am trying to get across. Sometimes walking out in a system and showing the person, is more of a "hands-on" approach which seems to work well with operators who are often very "hands-on" oriented.

- **Knowledge.** Knowledge is a good thing, but when what we know is not correct or not completely correct it may be challenging to accept a different understanding of something. Depending on the person it can be difficult to change someone's thinking. If you can correct or improve someone's knowledge this may take patience on your part, as well as a better understanding of the other person's thinking before you offer any alternatives. Think of the adventure of the ladies in the above story. I first got an understanding of their level of knowledge and understanding before coming up with an alternate plan to help them safely get out of the wilderness. I also didn't point out their lack of understanding.

- **Confusion.** A lot of times confusion can greatly reduce our understanding. For someone new coming into a facility refrigeration system, it can be very confusing trying to understand what controls what, and what goes where. Even for those who have years of experience when you go into a new facility, it takes time to get an understanding of the system. This may take weeks depending on how complicated a system or the systems are. To overcome confusion a person must put in the effort to learn and understand.

- **Determination.** No matter who we are we only gain more knowledge and understanding by the effort we are willing to put in. Decades ago, at my high school graduation, I heard one of my classmates say, "I am never going to read another book!" At the time I might have felt the same way, but I soon came to realize that was one of the dumbest things I ever heard. To get better, to gain knowledge and understanding you must read, study, ponder, test your knowledge, and make the effort to understand. A test is a celebration of knowledge and understanding. We improve by being determined to work at gaining knowledge, understanding, and experience. Many times, experience comes from making mistakes, hopefully, small ones, that increase our understanding for the next time something similar happens. We should be determined to continue learning and gaining understanding.

Young or old, just started or experienced, we can all improve our understanding to be better designers, installers, operators, educators, and even a better person. Keep working at it!

Hydrocarbon Standard Moves Forward with Public Review

The IIAR HC (Hydrocarbon) Standard has continued to move forward and was recently released for its first public review. The 45-day public review ran from July 7 through August 21. As of early August, the standard had received 92 comments.

"Having the standard out for public review is great progress. The committee has gotten it out in a good amount of time," said Dave Malinauskas, president at CIMCO Refrigeration and IIAR's board chairman.

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As part of the ANSI process, proposed standards have to be submitted to the public for comments, said Joseph Pillis, the IIAR HC subcommittee chair.

Tony Lundell, IIAR's senior director of standards and development, is the IIAR Staff facilitator for the IIAR HC Standard in Development, said the standard is 424 pages and includes general design and specific design for designing refrigeration systems that utilize natural hydrocarbon refrigerants, which have very low global warming potential.

The hydrocarbon standard follows a similar framework as the IIAR CO_2 standard and will serve as a complementary standard to ammonia and CO_2. Plus, this standard is intended to parallel/harmonize the ASHRAE 15 standard with general design requirements, which are building code requirements used by fire marshals.

"This IIAR HC standard also includes specific design, installation, startup, as well as inspection, testing, maintenance, decommissioning, and general safety equipment," Lundell said.

Pillis explained that the current draft of the standard covers the use of Propane, Butane, and Iso-butane in refrigeration applications, with the potential to add a few other hydrocarbons at a later date. "The standard has exceptions for listed systems and those systems for use in Chemical and Petrochemical applications. Listed systems are those built to UL standards, currently utilizing less than 150 grams of refrigerant per circuit," he said. "This amount will be increased over time as the UL standards for HC systems are revised."

For systems utilizing larger refrigerant quantities than covered by the UL standards (i.e., listed: equipment that has been tested and is identified as acceptable by an approved, nationally recognized testing laboratory) the refrigerant-containing equipment shall be installed in a machinery room or outdoors, Pillis said. "A secondary refrigerant would generally be used to transfer heat from the source to the hydrocarbon equipment," he said.

The natural hydrocarbon refrigerant, which remains in the machinery room, can be used as the primary refrigerant in a cascade system and/or for secondary systems that can chill and circulate a secondary fluid, such as a safe and different natural refrigerant (e.g., CO_2), brine or glycol.

The task force had already completed a pre-public review with select individuals, which received hundreds of comments. The pre-public review was designed to capture what is presently known and/or already being done as good engineering practices and to help make the public review period result in requiring fewer comments which will be more manageable. Pillis said he expects to receive a considerable amount of feedback as part of the public review.

The petrochemical industry has a long history of using hydrocarbons, and they are increasingly being used in some refrigeration applications where other refrigerants are not allowed, are difficult to use, or are inefficient.

"Hydrocarbons have been used as refrigerants for well over 100 years and they are well-understood and very efficient refrigerants. They are naturally occurring substances having minimal impact on the environment as they have no ozone depletion potential and very low global warming potential," Pillis said. "They are, however, highly flammable, and particular care must be taken in all aspects of their use to avoid the risk of fire."

A hydrocarbon standard is becoming even more critical as the government, industry, and private entities address refrigerants, and the hope is that a standard will allow systems to safely expand in size and quantity of refrigerant to increase capacity while being energy efficient.

For IIAR, developing a hydrocarbon standard was a natural extension of the association's mission to offer safe practice standards for other natural refrigerants as the use of low global-warming potential refrigerants grows.

After the public review, the committee works to address the received comments and develop responses for each quickly. Being a new standard, it is expected to have additional public reviews. The goal is to have the standard fully completed in 2024. The standard's purpose has been presented to the EPA SNAP (Significant New Alternatives Policy) Team for their understanding and consideration to get approval.

Lundell said the consensus from the SNAP team is that hydrocarbons can be used in industrial process refrigeration systems, including being the primary refrigerant for Cascade Systems and for chilling secondary fluids.

Those interested in getting involved in the development of responses to public comments can contact IIAR and express interest in joining the committee.

IIAR Board Advances Standards, Undertakes New Initiatives, and Celebrates Members

IIAR has recently had its June board meeting, and the board took action on several critical IIAR standards and initiatives, welcomed new committee chairs, and celebrated members who have devoted valuable time and expertise to the industry.

The board approved IIAR doing business as the International Institute of All-Natural Refrigeration to help demonstrate IIAR's role in advancing all types of natural refrigerants.

The board also approved releasing IIAR's Hydrocarbon Standard for public review, making it public on July 7. Don Faust, chairman of the Standards Committee, said three of IIAR's closed-circuit ammonia refrigeration system Standards, IIAR 5-2019 Startup, IIAR 6-2019 Inspection, Testing and Maintenance, and IIAR 7-2019 Developing Operating Procedures, are all in process of being updated, but none have publication dates for this year. Internal relief valve discussions are still underway. Additionally, IIAR 9-Minimum System Safety Requirements for Existing Systems will be getting an addendum later this year to address issues users have addressed making compliance difficult.

During the meeting, Wayne Borrowman, chairman of the CO_2 Handbook Committee, provided an update on the handbook. Three subcommittees are working to coordinate updates, and the objectives are to ensure the handbook is consistent and identify chapter revisions with timelines. The goal is to have updates completed later this year.

IIAR's board voted to establish a collaborative agreement with ANFIR, an advocate association in Mexico with similar goals and values as IIAR. Yesenia Rector, IIAR's meetings and international program director, discussed ANFIR's mission and said it would be a great partnership, similar to the relationships IIAR has in Costa Rica and Columbia.

Dave Malinauskas, president at CIMCO Refrigeration and IIAR's board chairman, proposed a new diversity and inclusivity initiative that he said is designed to encourage more people to join the industry. "The overarching goal is to ensure the IIAR is very welcoming to all. I think we need to be more inclusive, and we are putting together a policy for the IIAR staff, the executive committee, and all of the member organizations," he said. "In the policy, we commit to managing and measuring our progress. It isn't something that will happen overnight, but it will happen over time."

The board issued a special thank you and term completion award to Mark Stencel who served as the education committee chairman. Additionally, Borrowman was welcomed as the CO_2 Handbook Committee Chairman, Rob

For establishments with 100 or more employees in certain designated industries, the proposed requirement to electronically submit information from their Forms 300 and 301 to OSHA on an annual basis represents a change from the current regulation.

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Baker was named the Safety Committee Chair and John Flynn was appointed Education Committee Chair. Also, Mark Tomooka joined the Government Relations Committee.

Chuck Hansen, one of IIAR's founding members celebrated his 100th birthday, and the board recognized the milestone with a framed certificate signed by the board members and committee chairs making Chuck an Honorary Chair of IIAR. Hansen got involved in 1970 when there was a proposed change to the National Electric Code (NEC) that would have required the use of explosion-proof equipment in ammonia refrigeration engine rooms, a measure that would have proved ruinously expensive for the industry while doing little if anything to improve industry safety.

Chuck Hansen, one of IIAR's founding members celebrated his 100th birthday, and the board recognized the milestone with a framed certificate signed by the board members and committee chairs making Chuck an Honorary Chair of IIAR.

Hansen was one of four individuals who spearheaded the effort to develop a strategy to defeat the code change. Hansen helped create IIAR, signing the Documents of Incorporation in 1971 and becoming one of the original board members.

The board also approved IIAR's 2023-2024 fiscal year budget, and Malinauskas said the association is in a healthy financial state.

Built to Last

Creating Your Financial Legacy

All parents aspire to build a life for their children that is better than the one they lived. One way many parents seek to accomplish this worthy endeavor is by building a strong financial legacy. If you are fortunate enough to accumulate more wealth than previous generations of your family, you should work diligently to ensure that this wealth will translate to a financial legacy built to last not only for your children but for generations to come. The building blocks of a lasting financial legacy for your family may include lifetime gifts, proper estate planning, the appropriate utilization of life insurance, and open communication.

Lifetime Gifts

When contemplating your financial legacy, your attention may immediately shift to estate planning and the post-death transfer of wealth. Lifetime gifting, however, should not be ignored and can enhance any well-designed legacy plan. In 2023, an individual can make annual exclusion gifts valued at up to $17,000 per recipient without any estate or gift tax consequences. Gifts of any amount can also be made directly to educational or medical facilities on another individual's behalf without any estate or gift tax consequences. By incorporating lifetime gifts as part of your long-term financial legacy plan, you can reduce the size of your estate and mitigate potential future estate tax exposure. You can also help acclimate beneficiaries to their future inheritance while providing oversight and helping them develop financially responsible habits.

Proper Estate Planning

A proper estate plan is critical to leave a lasting financial legacy. A solid estate plan is built on the five core documents of estate planning – a revocable living trust, a "pour-over" will, a general durable power of attorney, a durable healthcare power of attorney, and an advance healthcare directive or living will. Once you have a solid foundation in place, you may want to discuss more complex estate tax planning strategies with an attorney if you believe estate taxes will be a concern.

When building your estate plan, you must ultimately decide how your assets should pass to future generations. While an outright gift of a beneficiary's inheritance may be the simplest option, you may instead choose to hold a beneficiary's inheritance in a further separate trust to help protect and preserve your financial legacy. If structured properly, trust assets will be protected from a beneficiary's creditors (including a divorcing spouse) despite the fact distributions can be made to help the beneficiary maintain his or her accustomed standard of living. Furthermore, because the beneficiary may not be considered the owner of the assets in the eyes of the law, the assets and future growth may avoid further exposure to the estate tax upon the beneficiary's death. In essence, this type of trust planning can help you preserve assets from generation to generation in a tax-efficient manner.

Appropriate Utilization of Life Insurance

You may choose to purchase a life insurance policy for a variety of reasons. One of those reasons may be to help mitigate the impact of estate taxes. This is particularly true if you plan to pass on illiquid assets, such as real estate or business interests, to your beneficiaries. An appropriate life insurance policy may help provide your beneficiaries with liquidity to pay any estate tax liability that may be due upon your death.

If you are the owner and insured of a life insurance policy, the value of the death benefit would be included in your estate. This would compound the estate tax issue you were trying to solve in the first place. As a result, you may consider working with an attorney to create an irrevocable life insurance trust (ILIT) to own the policy outside of your estate. If you transfer an existing policy to an ILIT, you must outlive the transfer by three years for the policy to be removed from your estate. However, if your ILIT purchases the policy directly, it will immediately be removed from your estate. To provide the trust with the funds to pay premiums, you can make annual contributions to the trust. These contributions will not have any gift tax consequences if the trust is structured properly, trust beneficiaries are notified of the contributions, and the contributions do not exceed the annual exclusion gift threshold multiplied by the number of trust beneficiaries.

Open Communication

In today's world, discussing one's finances with friends or family members (particularly younger generations) almost feels taboo. Although having these conversations may make you uncomfortable, you simply cannot avoid them. Doing so would be a disservice to your family and may jeopardize the lasting legacy you've worked tirelessly to build. Instead, you should embrace these conversations as an opportunity to educate younger generations about your specific intentions and finances in general.

When having these conversations, your first goal should be to provide your family with the basic information necessary to facilitate an efficient administration of your affairs. This information includes a list of assets, the location of assets, and the contact information for your team of trusted professionals (e.g., your attorney, accountant, and financial advisor). By ensuring your family members don't waste time tracking down key information, you will help facilitate a more efficient administration of your affairs from a time and cost perspective.

The second goal should be to help your family better understand the plan you have put in place. When doing so, you should be sure to provide insight into your decision-making process. For example, if your estate plan calls for gifts to charities or individuals who are not in your family, explain why you decided to make those gifts. If you decided to hold a beneficiary's inheritance in a further separate trust, explain the numerous benefits of doing so. While every member of your family may not agree with your decisions, these conversations will help them understand your decisions. If they understand your decisions, they are less likely to bicker amongst themselves or harbor resentment toward you or other family members.

The third goal of these conversations should be to educate younger generations and enhance their financial literacy. A sudden influx of available funds could be a tantalizing prospect for your beneficiaries. Without a basic understanding of issues such as personal finances, applicable tax laws, and creditor exposure, these beneficiaries may make irresponsible decisions. Even if you choose to hold a beneficiary's inheritance in further trust, the beneficiary may pressure a trustee to make ill-advised distributions for his or her benefit. Just one poor decision caused by a lack of understanding can jeopardize the legacy plan you worked so hard to build.

Leaving a lasting and meaningful financial legacy requires discipline and significant planning. The concepts addressed in this article may help you advance toward your ultimate goal. Nonetheless, you should work closely with your financial advisor and estate planning attorney to create and maintain a plan that addresses the specifics of your unique situation.

IMPORTANT DISCLOSURES

The IIAR and NRF reserve investment funds are currently managed by Stifel Financial Services under the investment policy established by their respective board of directors. Members of IIAR may use the services of Stifel for personal and business investments and take advantage of the reduced rate structure offered with IIAR membership. For additional wealth planning assistance, contact your Stifel representative: Jeff Howard or Jim Lenaghan at (251) 340-5044.

Stifel does not provide legal or tax advice. You should consult with your legal and tax advisors regarding your particular situation.

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IIAR Remembers

Klaas Visser

IIAR's success hinges on the involvement of its members. The association would like to pay tribute to Klass Visser, who recently passed away. Klass authored the technical paper that follows this memorial, and we would like to honor his memory and express our gratitude to him for all the shared time and expertise with IIAR and the industry over the years. He will be missed.

Klaas Visser, known to the natural refrigeration industry as a relentless environmental advocate who is credited by many for helping lead the renaissance of CO_2, as well as a tireless innovator who introduced pivotal new refrigeration system designs, has passed away at the age of 83.

Klaas, who was the owner of Australia-based KAV Consulting, is remembered by friends and colleagues around the world as a passionate educator, mentor, and friend with the rare gift of inspiring enthusiasm and connection wherever he went.

"I came to know him as an articulate, passionate, and very clever man who had ideas that were beyond the thoughts of most people, which, if implemented, would help our planet in the long term," said Ian Tuena, Director of C.A. Group Services. "He continued to strive towards this end with his CO_2 work [even at the end of his life] into the early part of 2023."

"One of Klaas's passions was to pass on as much of his knowledge as he could. He was a motivational leader and encouraged others to share his enthusiasm for delivering innovative solutions. Klaas has given me, and many others opportunities and support to grow and succeed and I will always remember him as a great friend and mentor," said John Mott, former General Manager of Gordon Brothers Industries.

"He was one of those amazing refrigeration experts who had that combination of practical experience, common sense, and exceptional understanding of theory and thermodynamics," said President Emeritus, IIAR, Kent Anderson. Adding that, "you could learn a lot [from any conversation with Klaas]."

Born and educated in the Netherlands, Klaas graduated with a degree in marine engineering. After arriving in Australia in 1964, Klaas studied mechanical engineering at the Royal Melbourne Institute of Technology, then went to work for Wildridge and Sinclair, where he began his career designing ammonia refrigeration systems for the food and cold storage industries. That led to a position at McNiece Brothers in Bendigo where he managed the refrigeration division through the mid-seventies. Klaas left McNiece to start his own consulting business in Bendigo, where he developed a large-scale plate freezer design that was later widely adopted by the meat industry.

"Klaas was highly respected in the meat industry, and also known for being tenacious in backing his signature projects," said friend and colleague, Brendan Dever.

Klaas contributed many technical papers to the industry over the years. Among several recognitions was the James Harrison Medal in 1997, Australia's most prestigious award for the refrigeration and air conditioning industries, and IIAR's award for presentation excellence for his 2017 IIAR technical paper, "The Design of CO2 Refrigeration System Using Ammonia System Design Principles."

Klaas made two massive contributions to the development of refrigeration technology during his career, said Andy Pearson, Group Managing

Director of Star Refrigeration. The first, in the 1970s, was the development of novel plate freezing techniques for the meat industry, including large horizontal plate freezers for boxed meat and cartonless moulds for more efficient freezing.

His second major contribution was in speeding up the adoption of transcritical CO_2 systems in Australia, recognizing that there were opportunities to take plant performance beyond industry norms to deliver advantages in transitioning from HFCs.

"Klaas had a significant input in the design of plate freezers and use and effectively drove the change from tunnel freezing in the Australian meat industry to plate freezing," said Tuena. "His passion and belief in the renaissance of CO_2 also had a significant influence on the adoption of transcritical CO_2 systems in Australia and dispelled the myth that transcritical CO_2 systems were not suitable for warm climate countries like Australia."

In his work with CO_2, Klaas carried forward the work of Gustav Lorentzen, considered the father of the modern CO_2 refrigeration cycle, whom Klaas regarded as a friend and mentor.

"Klaas explained to Ian Tuena a couple of weeks ago that the highlight of his life was when his work was endorsed by Prof. Gustav Lorentzen," said Stefan Jensen, Managing Director of Scantec Refrigeration. "Indeed, Klaas continued Lorentzen's vision for the revival of CO_2 as a refrigerant almost until the end [of his life]."

Tuena, who worked with Klaas on his first foray into CO_2 transcritical work in Australia remembers a project to replace multiple freon-based systems for Exquisine Foods, a dairy foods manufacturing facility in Northcote.

"When I look back at that project (which is still fully operational today) and with the advantage of hindsight, I now see how visionary that project actually was," said Tuena. "The low temp rack serviced the -40c blast and -20c store, the med temp rack serviced the +2c and + 10c areas, he had parallel and intermediate temperature compressors servicing the flash gas load and AC load way before it was common practice to do so. He utilized the heat recovery achieving +18c to +80c in a single pass. It was a real credit to both Klaas, for taking the initiative and believing in transcritical CO_2 and David Rose for supporting him. They showed transcritical CO_2 systems were an environmentally friendly and economically viable solution for Australian refrigeration systems and paved the way for the expansion we now see within the supermarket and industrial industry throughout Australia and New Zealand."

Mitchell, a friend and colleague.

Currently, said Roy Robinson, "more than 85% of the frozen red meat exported from Australia is frozen in Plate Freezers. The initial development works done by Klaas with Federal and industry funding have come to fruition, with the resultant massive reduction in greenhouse gases. Klaas has that achievement as one of his many legacies."

Brent Hoare, the founder, and director of the Green Cooling Association, which later became the Australian Refrigeration Association, remembers the contribution made by Klaas in supporting natural refrigeration, especially in Hoare's work advocating for natural refrigerants at the Montreal Protocol negotiations.

Klaas and Brendan Dever with cartons exiting the prototype plate freezer at Tancreds Beaudesert.

As much as Klaas was remembered for his technical innovations, friends remembered him even more for the passion that drove those innovations . . . his concern for the environment.

"The plate freezer concept as many have mentioned has changed the meat industry in Australia but he also had a desire to make things better for this planet and humanity as a whole by improving refrigeration systems which were more energy efficient but also greener," said Carin

"Klaas made such a huge contribution to this industry, and his name deserves to be remembered for a long time to come," said Hoare. "Klaas devoted his life to establishing CO_2 and Ammonia as the solution to large refrigeration applications. He had a brazen fearlessness in speaking truth to power and challenging the dominance of hydrofluorocarbons. It's up to all of us – the people in this industry – to remember his passion around advocacy and carry it on."

The following technical paper won the award for excellence at IIAR's 2017 Annual Meeting and Convention. It appears here as a memorial to its author, Klaas Visser, who is remembered by friends and colleagues as a tireless contributor to the work of the natural refrigeration industry.

TECHNICAL PAPER #2

The Design of CO2 Refrigeration System Using Ammonia System Design Principles

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ABSTRACT

Over the past 20 years or so the use of CO2 refrigerant as the first stage of CO2/HFC and CO2/NH3 cascade systems has increased significantly. The use of two-stage transcritical CO2 systems, which are invariably air cooled, is an increasing trend. Frequently, two-stage gas coolers are used with water sprayed on the secondstage air-cooled gas coolers to reduce the gas cooler exit temperature to as low a value as possible.

The latest trend is using ejectors to partially recompress the flash gas with the transcritical gas coolerexit fluid in an effort to improve the very poor coefficients of performance (COPs) resulting from gascooler exit temperatures significantly higher than the CO2 critical temperature of 31.1°C (88°F). COP improvements of 10–30% have been reported when using ejectors.

This paper demonstrates that the application of evaporative condensers, which are commonly used in ammonia refrigerating systems, to condense subcritical CO2 and gas cool transcritical CO2 fluid will permit the efficient application of CO2 refrigeration worldwide if ammonia design principles are followed.

By using the ambient wet bulb design temperature (AWBDT) as the condensing and gas cooling base temperature instead of the ambient dry bulb temperature, all CO2 refrigeration applications are brought within the scope of efficient applications worldwide. CO2 refrigeration that employs evaporative condensers and gas coolers, if used with parallel compression, will be at least as efficient, if not more efficient, than ammonia refrigerating systems.

Once the CO2 refrigerant is in a subcritical condition it behaves much like ammonia, and hence ammonia refrigerating system design principles become appropriate. However, thermophysical properties of CO2 require adjustment in the values of separation velocities in accumulators and suction traps and values are recommended in the paper. Similarly, several tables in the paper show the capacities of dry suction and wet return lines and liquid lines capacities.

Oil separation techniques and automatic oil return methods in both CO2 direct expansion (DX) and liquid recirculation systems are explained and design guidelines are provided.

INTRODUCTION

The author acknowledges his late dear friend Prof. Dr. Gustav Lorentzen for reviving his interest in CO2 refrigeration in the mid-1980s when the ozone depletion potential of CFCs and HCFCs became evident (see Figure 1). This resulted in the Montreal Protocol (MP) to phase out the use of CFCs and HCFCs and to prohibit their production and use after certain dates. We celebrate Gustav Lorentzen's 1993 public call for the revival of the use of CO2 every two years with the IIR Gustav Lorentzen Natural Refrigerants Conference (IIRGLNRC). The first of these was held in Hanover, Germany, in May 1994. The 12th IIRGLNRC was conducted in Edinburgh, Scotland, in August 2016.

The eminent refrigeration scientist Dr. S. Forbes Pearson designed the first application of CO2 in the modern era in 1992. The system comprised two flooded CO2 evaporators in which the CO2 vapor is condensed in an ammonia-cooled plate heat exchanger. A demonstration unit was installed in a small -23°C cold store at Marks and Spencer p.l.c., Kilmarnock, Scotland. CO2 hot gas for defrost was generated in a CO2 boiler heated by ammonia from the discharge of the ammonia compressor (Pearson 1992).

The term revival of CO2 is correct. As Professor Risto Ciconkov of The Saints Cyril and Methodius University of Skopje in Macedonia shows so eloquently in Figure 2 (private communication), CO2 and ammonia were commonly used in all manner of cooling and freezing applications from the 1870s to the 1940s, including cooling for human comfort, e.g., the cooling in some cinemas in Sydney until about 1966. But after the advent of CFCs (R12, etc.) in the 1930s, the use of CO2 rapidly declined.

Luckily ammonia (NH3) survived as a natural refrigerant for industrial applications.

BACKGROUND

The author has personal experience with CO2 refrigeration on board a ship, which took frozen meat east from Buenos Aires, Argentina, to Yokohama, Japan. A CO2 plant provided refrigeration. Gustav Lorentzen described a similar experience as a young man before World War II sailing between Norway and China. The author's main CO2 design experience was gained with the design of a multifunction two-stage transcritical CO2 refrigerating system with parallel compression (MF2STC-CO2RSPC). In September 2009, Exquisine Pty. Ltd. decided to install a two-stage transcritical CO2 refrigeration plant to replace 22 independent systems providing heating and cooling at its Thornbury, Victoria, food-processing facility where high-end frozen dairy desserts are manufactured. The system was supported by a 50% grant from AusIndustry, an Australian federal government department, under the Re-Tooling for Climate Change program. A CO2/ammonia cascade plant was briefly considered, but with residential properties bordering the site, it was judged best not to use ammonia. Plant noise was also a potential problem (Visser 2012).

The new two-stage transcritical CO2 refrigeration plant carries out all the required blast freezing, cold and chilled product and ingredient storage, factory and packing area cooling, and chilled process water cooling. In addition the system heats all potable tap water for sanitary and factory cleaning purposes. Process hot water is also partially generated to provide A/C reheat and space heating for the office and factory. A secondary ethylene glycol circuit provides underfloor and door jamb heating for two large cold store and three blast freezer doors and highly effective freezer evaporator defrost.

The 22 existing systems being replaced by the new system comprise four individual systems for blast freezing and cold storage—one of each—and two chillers. In addition are one independent chilled water system, one evaporative cooler used for factory cooling, four reverse cycle office A/C units, six air-to-water heat pumps, three gas-fired mains pressure hot water systems, and four electric underfloor and freezer door circuits. One of the most critical parts of the design was the oil management. To that end the six transcritical compressors were each equipped with an oil separator, while the three boosters share one unit. The specific savings per unit production amount to a 33% reduction in electrical energy consumption, a 60% reduction in natural gas consumption, a 44% reduction in direct and indirect global warming emissions, and a 40% reduction in cooling water consumption (Visser 2012).

This 2010 full-scale prototype plant employed a two-stage gas cooler with water spray on the second stage. Observations of the somewhat erratic operation led to the idea that an evaporative condenser (EC) would greatly improve the situation (Ball and Visser 2015; Visser 2014a, b, d, 2015a). Hence the second MF2STCCO2RSPC now under construction for a cook/freeze facility for the NSW Department of Corrective Services near Sydney incorporates an evaporative condenser.

ADVANTAGES AND DISADVANTAGES OF R744 (CO2)

The advantages and disadvantages of CO2 as a refrigerant are summarized below.

Advantages

Advantages of R744 include the following:

Table 1. Cooling capacity for a commercially available reciprocating compressor with a swept volume of 57 cfm at 1,480 rpm *Source: Pachai et al. (2001).*

Refrigerant	Cooling Capacity (TR) Evaporator Temp. / Condensing Temp. (TE/TC) = −22°F/+23°F
R744	64.7
R717	7.2
R22	8.8

Table 2. Compression ratios for R744, R717, and R22 *Source: Pachai et al. (2001).*

TC/TE (°F)	R744	R717	R22
23 / −13	1.81	2.34	2.10
23 / −22	2.13	2.97	2.58
23 / −31	2.53	3.81	3.20
23 / −40	3.03	4.95	4.02
23 / −49	3.66	6.51	5.09
23 / −58	4.66	8.67	6.54
23 / −67	5.49	11.77	8.52

High volumetric performance

In the range of –55°C (–67°F) to 0°C (32°F) evaporating temperatures, the volumetric performance of CO2 is 4–12 times better than that of NH3. This means that CO2 compressors and suction piping systems are smaller than for equivalent capacity NH3 systems. See Figures 3 and 4 and Table 1.

Low compression pressure ratio

In the case of CO2, the compression ratio is about 20 to 50% lower when compared with HFCs and ammonia. See Figures 3 and 5 and Table 2.

The lower compression ratio combined with the higher pressure levels give greater volumetric and isentropic efficiencies. Stoecker (2000) quantified the beneficial impact of the combination of low compression ratios and higher pressure on both the volumetric and isentropic efficiencies. See Figures 6 and 7.

The overall benefit of low compression ratios is that the real relative COP (immediate COP) is 15 to 20% higher than the theoretical relative COP in the case of CO2. See Figure 3d.

High heat transfer during evaporation

Figure 8 presents a very interesting comparison and variation of the overall heat transfer coefficient of CO2 and R22 with logarithmic mean temperature difference (LMTD). A most outstanding feature of CO2 is the almost constant U-factor for CO2 with LMTDs ranging from 3 to 18°F.

In practice, this means that CO2 evaporators may be made significantly smaller and low air-to-refrigerant approaches are possible in heavy-duty low temperature freezing applications. Increasing the mass velocity in the refrigerant circuits also enhances evaporator performance. This is possible as evaporator circuit pressure

drops 7–10 times higher for the same drop in saturation temperature are allowable in CO2 evaporators. This means fewer evaporator circuits with higher circuit loading at relatively low recirculation rates compared with NH3 (say n = 1.5 for CO2 instead of n = 4 for NH3). See Figure 9 for saturation temperature drop with respect to pressure drop.

Considering Figure 10, clearly CO2 used as a one-phase liquid brine is superior in every respect compared with other brines in terms of temperature difference—heat transfer—and pressure loss factors. CO2 may also be used as a volatile brine as demonstrated by Pearson in 1992.

CO2 may be used in direct systems in the spaces to be cooled, which would give the highest possible evaporating temperature at the highest efficiency.

Inert gas

CO2 is an inert gas, and hence the choice of metallic materials for piping and components generally does not present a problem provided dry CO2 is used and the system components can handle the maximum design pressures. Attention must be paid to the compatibility of elastomers in contact with CO2 (gaskets, o-rings, etc.).

Environmental implications

With respect to global warming potential (GWP), the effect of CO2 refrigerant escaping into the atmosphere is neutral as CO2 is already present in the air. Although CO2 is a greenhouse gas, its use as a refrigerant will be completely neutral because CO2 is a byproduct of existing processes (internal combustion engines, thermal power generation) or as part of an ecological cycle. Allowing the GWP of CO2 is one, it can be argued that CO2 sequestered in a refrigeration system has a GWP of zero.

Occupational health and safety

In Australia, the threshold limit value (TLV) is 5,000 ppm with a short-term exposure limit (STEL) of 30,000 ppm. These numbers were set in 1990. The TLV of 5,000 ppm is almost universally accepted with STEL levels varying between 10,000 to 30,000 ppm with time limits imposed on the duration of exposure.

CO2 cannot burn or explode. Also, at very high temperatures, such as during a fire, CO2 does not create hazardous gases, such as phosgene and hydrofluoric acid, which are created at high temperatures with CFCs and HCFCs, and hydrofluoric acid and carbonyl fluoride, which occur when incinerating HFC at high temperatures.

Figure 11 clearly shows that in the case of evaporators with identical circuit pressure drops, CO2 is superior to both HFCs and ammonia.

Existing CO2 production facilities

Compared with the present production and consumption of CO2, the consumption of CO2 by refrigeration plants in future will be very small indeed.

Low cost and lower required volume

CO2 is quite cheap when bought in industrial quantities. The pure CO2 required for refrigeration will not cost more than ammonia and will cost a fraction of the high cost of modern HFCs and a small fraction of the new HFO refrigerants that are now promoted to replace high GWP HFC under the auspices of the MP. The highly poisonous combustion gases from burning HFOs raise serious concerns. This has led three leading members of the German Motor Vehicle Association—Mercedes Benz, BMW, and the Volkswagon Group—to opt for CO2 refrigeration mobile air condition (MAC) applications.

Because of smaller pipes, evaporators, and compressors, a smaller

Table 3. Estimated net and raw COPs of a semihermetic CO2 compressor with an air-cooled gas cooler, including a 25% improvement due to the use of an ejector, on the first expansion stage to 23°F saturated suction and 9°F suction superheat

Discharge pressure, psi	1,100	1,177		1,324		1,471		1,618		1,765		1,765	
Ambient cooling air temp., °F	Gas cooler exit temp., °F	Compressor COPs											
		Raw	Net	Raw	Net	Raw	Net	Raw	Net	Raw	Net	Raw	Net
77	86	3.58	3.22	3.49	3.14	3.20	2.88	2.94	2.64	2.71	2.44	2.50	2.25
86	95	1.04	0.93	1.98	1.78	2.76	2.49	2.64	2.37	2.46	2.22	2.29	2.06
95	104	0.53	0.47	0.99	0.89	1.90	1.71	2.23	2.00	2.18	1.96	2.06	1.86
104	113	0.24	0.21	0.54	0.48	0.99	0.89	1.61	1.45	1.81	1.63	1.80	1.62

volume charge of CO2 may be required compared with an ammonia system of equivalent capacity. However, note that the density of liquid CO2 compared with liquid NH3 is about 1.5 times higher. This means that for large industrial systems with most of the liquid refrigerant in pump recirculators and pump-feed evaporators (large plate freezers, large air coolers, etc.), the mass charge of CO2 will be usually larger than for a comparable NH3 system—even if the volumetric charge should be somewhat smaller.

High operating pressure

The high operating pressure is an advantage as it permits the compressor discharge pressures to reduce to low levels with diurnal and seasonal variations in ambient dry and wet bulb conditions. This produces high average COPs resulting in CO2 plants being more efficient than all other refrigerating plants using ammonia, hydrocarbons, HCFCs, HFCs, or HFOs.

Easy to service

CO2 may be blown off when servicing refrigeration system components, as it is harmless and cheap. However, special procedures are required to ensure that no dry ice is formed in a system when it needs to be opened up.

Disadvantages of CO2

The temperature ranges from the triple point at −56.6°C (−69.9°F) and the critical temperature of +31°C (87.8°F), which limits the application in conventional air- cooled refrigeration cycles. See Figure 12.

High design pressure

When air-cooled CO2 systems are built, they need to be designed for up to 120 bar maximum working pressure (MWP) for transcritical operations in an effort to maximize energy efficiency, which is generally very poor even with band-aids like ejectors (see Table 3 and Figure 13). Existing high-pressure compressed natural gas (CNG) compressors suitable for pressures up to 350 bar and crank case pressure up to 70 bar are very likely suitable to be modified for high-pressure CO2 operations with appropriate piston, cylinder, and valve configurations for high mass flows. The high pressures do not cause a major increase in risk, as the risk is determined by the energy content of the system, i.e., the pressure times the volume (p x V). In CO2 systems the volume is very small compared with conventional refrigeration systems and thus the higher pressures do not result in an increase in potential energy if a sudden rupture occurs.

Special precautions, equipment, or procedures for long shut-down periods of CO2 plants

CO2 plants for low-temperature operation with design pressures up to 52 bar require special consideration as follows:

- Use a small, independent CO2-condensing unit to re-condense CO2 vapor and expand the CO2 back into the system. Ensure that an independent power supply, such as a diesel-driven generator to start the system automatically when required, is included.
- Control pressure by means of CO2 vapor re-condensing using a small independent HFC or ammonia refrigeration unit with a diesel engine driven compressor or generator.
- Locate the low-pressure receiver and/or intercooler in a refrigerated warehouse at temperature of 0°C (32°F) to −30°C (−22°F). Alternative methods are fade-out vessels or controlled blow off.

High density of CO2 vapor

Like CFCs, HCFCs, and HFCs, CO2 is denser than air and tends to displace the atmosphere. In confined spaces (basements, ship holds) CO2 could reach high concentrations. Any person entering such a space would risk health damage. In practice, this is considered to be a manageable risk with proper leak detection and space ventilation in place.

Furthermore, CO2 is odorless and as such will not be noticed by people when entering a space containing a high concentration of CO2. Thus, reliable portable CO2 detectors are required to ensure personnel safety in confined spaces. Short-term exposure levels to CO2 concentrations above 60,000 ppm (6%) are still tolerable, but can be fatal if exposure is too long.

EXAMINATION OF ENERGY EFFICIENCY OF CO2 REFRIGERATION SYSTEMS

The COPs of semiautomatic CO2 compressors are based on motor input, while open ammonia compressor COPs are based on power input into the compressor shaft, i.e., BkW or brake horsepower. When comparing these COPs, semihermetic CO2 compressors are at a disadvantage. An electric motor efficiency of 90% has been assumed for the electric motors driving the semihermetic compressors to arrive at estimated values for raw COPs based on compressor shaft power input. This allows COPs of semihermetic and open compressors to

Table 4. Variation of raw and net COPs of a semihermetic CO2 compressor with condensing temperature and liquid subcooling at 32°F saturated suction temperature (SST)

Parallel Compression, A/C Duty			
SCT, °F	COP @ 32°F SST		LSC, °F
	Raw	Net	
60.8	9.21	8.29	5.4
64.6	8.3	7.47	7.2
68	7.52	6.77	9
71.6	6.87	6.18	10.8
75.2	6.29	5.66	12.6
78.8	5.79	5.21	14.4
82.4	5.34	4.81	16.2
86	4.94	4.45	18

Table 5. Variation of raw and net COPs of a semihermetic CO2 compressor with condensing temperature and subcooling at 23°F SST

High Stage Duty			
SCT, °F	COP @ +23°F SST		LSC, °F
	Raw	Net	
60.8	8.66	7.79	37.8
64.6	8.03	7.23	41.4
68	7.48	6.73	45
71.6	7.0	6.30	48.6
75.2	6.56	5.90	52.2
78.8	6.17	5.55	55.8
82.4	5.82	5.24	59.4
86	5.49	4.94	63

be compared on an equal basis.

The excellent heat transfer properties of CO2 allow CO2 condensing at 30°C (86°F) saturated condensing temperature (SCT) at an ambient wet bulb design temperature (AWBDTs) of 24°C (75.2°F) to 25°C (77°F). Gas cooler exit temperatures of 30 to 31°C (86 to 87.8°F) are achievable with AWBDTs of 28°C (82.4°F). An AWBDT of 28°C (82.4°F) is not exceeded in 98% of the world's climates.

In the following sections all CO2 compressor capacities and energy consumption values used are from one manufacturer, which only manufactures semihermetic compressors. In Tables 4 and 5 and Figures 14 and 15 the net COP is based on the electric motor input while the raw COP is based on a 90% electric motor efficiency. An isentropic efficiency of 75% has been assumed and closely matches derived values. The raw COPs listed in Tables 6 and 7 are shown graphically in Figures 16 and 17.

Clearly the gas cooler exit temperature has a major impact. Therefore cooling transcritical CO2 fluid with a coolant temperature close to or above the critical point of CO2, 88°F, is thermodynamic nonsense. The industry understands this well as COPs are very low. In an effort to improve the COPs of ambient air-cooled

transcritical CO2 systems, ejectors are increasingly used to compress some of the flash gas vapor from the first expansion stage and, increasingly, in additional applications. The entry cooling air approach at the gas cooler CO2 exit is 9°F in an air-cooled transcritical CO2 refrigeration cycle. Minetto et al (2015) and Kriezi et al (2015) have reported COP improvements of 6 to 25%. In Table 7 the net and raw COPs are plotted at six discharge pressures from 1,100 to 1,765 psi, which include a 25% increase on COP due to (an) ejector(s) being used. Figure 17 plots the six sets of COP values.

Clearly the COPs in Figure 17 compare very unfavorably with COPs in Figures 13–16, which are based on evaporative condensers/gas coolers (EC/GCs). This is to be expected because in EC/GCs the ambient wet bulb temperature becomes the initial coolant temperature rather than the ambient air dry bulb temperature, which is the coolant temperature in air-cooled systems. Manufacturers of air-cooled gas coolers realize that air-cooled gas coolers have limitations and offer their products with water sprays on the gas cooler coil face that are activated during hot weather. It is only a small step from this wasteful use of water to full evaporative condensing. Pearson comes to a similar conclusion (2010).

DESCRIPTION OF A CO2 REFRIGERATING SYSTEM FOR A MEAT PACKING PLANT AND ESTIMATED LOADS

A medium size meat packing plant for beef has been chosen as a working example.

Plant production definition

At this plant 1,000 head of bovine livestock are converted into beef with an average dressed weight of 770 lb/head. Thus the total daily carcass weight production is 770,000 lb. The carcasses are chilled in hot boxes before entering the fabrication rooms (FR) for deboning, yielding about 70% producing about 540,000 lb of red meat. Seventy percent of this, i.e. 378,000 lb, is frozen with 72,000 lb of edible offal like hearts, livers, kidneys, etc. Process areas like the Fabrication Room, offal packing room, load out, and office and welfare areas need cooling as well. See Figure 18.

Refrigeration loads

Process areas:

- Space cooling:
  - FAB Room and offal packing, 130 TR;
  - Load out, palletizing area, and condensation control, 90 TR;
  - Office and welfare A/C, 24 TR; and
  - Total refrigeration load, 244 TR;
- Parallel compression:
  - Total flow from +68°F to +32°F equals 1,205 lb/min;
  - Enthalpy loss: 61.505 – 37.47 = 24.035 BTU/lb;
  - Heat load: 1,205 x 24.035 x 60 = 145 TR; and
  - 12,000; and
- Total space cooling and parallel compression @ 32°F saturated suction: 389 TR;

Chilling loads:

- Hot boxes, 171 TR;
- Carcass beef holding, 14 TR;
- Chilled process water, 26 TR;
- Chilled carton store, 22 TR; and
- Total chilling loads, 233 TR;

Table 6. Variation of raw and net COPs with gas-cooled exit temperatures at 32°F SST when operating in transcritical mode at 1,100, 1,177, and 1,324 psi discharge pressure

Parameter			Values of parameters					
No	Description	Unit						
1	SST	°F	32		32		32	
2	Discharge pressure	psi	1,100		1,177		1,177	
3	Suction superheat	°F	36		27		27	
4	Useful superheat	°F	9		9		9	
5	Discharge temperature	°F	192		192		192	
6	COP, net, raw @		Raw	Net	Raw	Net	Raw	Net
7	Gas cooler exit temperature, °F	68	4.32	3.89	4.15	3.73	3.79	3.42
8	Gas cooler exit temperature, °F	59	4.65	4.19	4.46	4.01	4.07	3.66
9	Gas cooler exit temperature, °F	50	4.95	4.45	4.73	4.26	4.31	3.88
10	Gas cooler exit temperature, °F	41	5.20	4.68	5.00	4.51	4.52	4.07
11	Gas cooler exit temperature, °F	32	5.47	4.92	5.25	4.72	4.77	4.29

Table 7. Variation in raw and net COPs with gas cooler exit temperatures at +23°F SST when operating in transcritical mode at 1,100, 1,177, and 1,324 psi discharge pressure

Parameter			Values of parameters					
No	Description	Unit						
1	SST	°F	23		23		23	
2	Discharge pressure	psi	1,100		1,177		1,324	
3	Suction superheat	°F	32		27		18	
4	Useful superheat	°F	9		9		9	
5	Discharge temperature	°F	194		205.7		214.7	
6	COP, net, raw @		Raw	Net	Raw	Net	Raw	Net
7	Gas cooler exit temperature, °F	68	3.84	3.46	3.51	3.16	3.28	2.95
8	Gas cooler exit temperature, °F	59	4.13	3.72	3.78	3.40	3.49	3.14
9	Gas cooler exit temperature, °F	50	4.39	3.95	4.02	3.62	3.67	3.31
10	Gas cooler exit temperature, °F	41	4.61	4.15	4.23	3.80	3.89	3.50
11	Gas cooler exit temperature, °F	32	4.87	4.39	4.43	3.99	4.07	3.66

Low-temperature loads:

- Plate freezing, 450,000 lb, 297 TR;
- 600,000 ft3 cold store, 57 TR;
- Oil still, 37 TR; and
- Total LT load to boosters, 391 TR;

High-stage load:

- Discharge boosters;
- From boosters @ COP = 3.96, 490 TR;
- Subtract booster discharge desuperheating, 87 TR;
- Net booster discharge to high stage, 403 TR;
- Chilling loads from 2.5, 233 TR; and
- Total high-stage load, 636 TR.

Figure 18 — Simplified CO2 refrigerating system schematic including water heating circuit

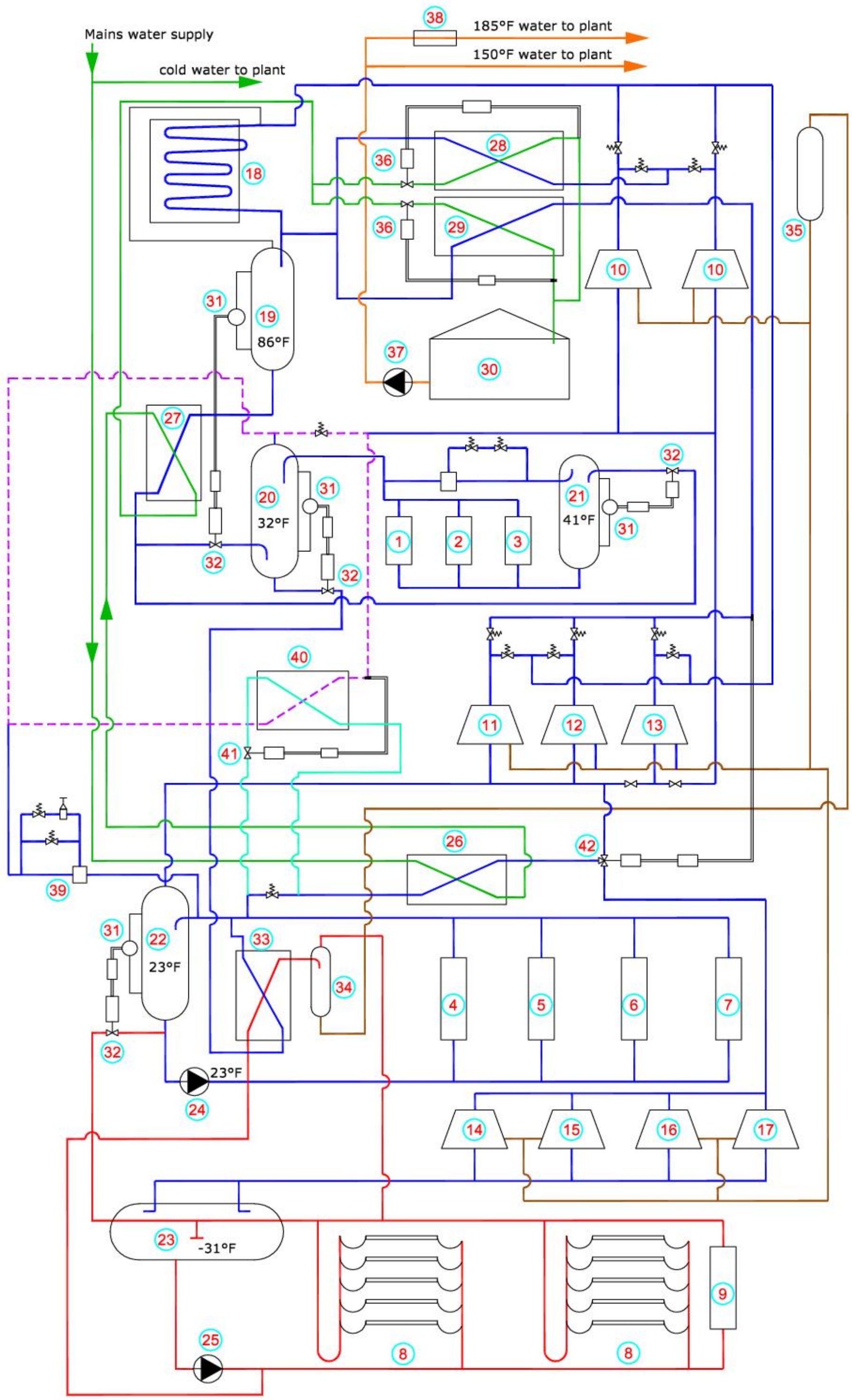

Figure 18 Legend Schematic Drawing

Item	Description
1	Process area cooling
2	Load out cooling
3	Office and amenities cooling
4	Active carcass chiller
5	Active carcass chiller
6	Quarter beef chillers
7	Chilled water linear chiller
8	Plate freezer
9	Cold store
10	Process cooling/CO_2 parallel compressor
11	High stage CO_2 compressors
12	High stage CO_2 compressors
13	Standby CO_2 compressor for 10 – 12
14	CO_2 booster compressor
15	CO_2 booster compressor
16	CO_2 booster compressor
17	CO_2 booster compressor
18	Hybrid CO_2 evaporative condenser
19	Pilot liquid receiver
20	32°F suction trap for 1, 2 & 3 & flash off vessel
21	41°F pressure receiver for 0°C DX evaporators 1, 2, 3
22	23°F inter cooler / pump accumulator
23	−31°F low pressure receiver / pump accumulator
24	23°F CO_2 liquid pumps to chillers loads, 4, 5, 6, 7
25	−31°F CO_2 liquid pumps to plate freezers and cold store, 8 & 9
26	Booster discharge desuperheater – water cooled
27	Water cooled CO_2 liquid sub-cooler
28	Process water heater in parallel compressor discharge
29	Process water heater in high stage compressor discharge
30	150°F hot water storage tank – 150,000 to 200,000 gallons
31	Differential Pressure Sensor (DPS)
32	CO_2 liquid flow control valve
33	Oil still evaporator
34	Oil collection vessel
35	Oil storage distribution vessel
36	Exit water temperature water flow control valves controlled by exit water temperature
37	150°F hot water pump
38	Gas fired water heater
39	AC//parallel (ACPC) compressor suction pressure regulator and bypass
40	AC//parallel compressor suction superheater
41	AC/parallel compressor suction superheat regulator controlled by suction vapor temperature to ACPC. Alternative control from ACPC discharge temperature
42	High stage compressor (HSC) discharge temperature regulator by controlling booster discharge vapor rate of injection into HSC suction

COMPRESSOR DISCHARGE AND PUMPED LIQUID AND WET RETURN PIPING

Tables 10–14 summarize the pumped liquid lines sizes for liquid recirculation (LR) rates of 1, 1.5, 2, 3, and 4 to 1. These capacities are based on a constant pressure loss of 6.6 ft/100 ft equivalent pipe length. Equivalent pipe length is defined as the length of straight pipe to which the equivalent lengths of all valves, strainers, bends, tees, impact of branch connections, etc., are added. Table 9 lists these equivalent length factors. The equivalent pipe length is the factor multiplied by the valve or fitting size in feet.

Tables 15-18 show wet return line sizes for LR rates of 1, 1.5, 2, and 4 to 1. These calculations are based on basic software developed by Stefan Jensen in 1986 and updated by the author's collaborator and scientific supporter John Ball.

Using the tables sizing compressor discharge lines, liquid drain lines from the receiver, liquid lines from the receiver to the +41°F vessel to the +32°F AC/parallel compressor suction trap, and from there to the intercooler and pump suction lines is not possible.

EVALUATION OF CO2 COMPRESSOR MASS FLOWS AND VAPOR DISPLACEMENT

To calculate the high-pressure liquid lines we need to know the mass flows in the liquid lines. In Table 19 the mass flows to the 41°F AC/compressor suction trap, the +23°F chiller accumulator/intercooler, and the –31°F freezer accumulator are evaluated as are the CO2 vapor volumes generated. The approximate ammonia swept volumes at identical conditions are determined and compared with the calculated CO2 swept volumes.

In Table 1 the capacity of a 57 cfm subcritical CO2 compressor is nine times greater than the ammonia capacity of the same compressor at identical operating conditions. In Table 9 a CO2-to-ammonia swept volume ratio of 7.61 is calculated at an 11°F lower saturated suction temperature. The difference is most likely due to the author assuming a lower volumetric efficiency.

At 85% volumetric efficiency the calculated swept volumes of the AC and high- stage CO2 compressors are about 5% greater than those quoted for well-known, commercially available semihermetic trans- and subcritical CO2 compressors. The author is therefore confident in the results of the tabulated calculations in Table 19.

The data in Table 19 has been used to size all the compressor discharge headers shown in Table 20. The compressor discharge temperatures were taken from manufacturers' compressor data and the CO2 velocities in the lines were assumed as reasonable values.

Table 8. Sizing of major CO2 pipes using Tables 10 - 18

Pipe definition			Length, ft			CO_2 feed	Pipe size determination		
							Table No.		
No.	Function description	Capacity, TR	Linear length	Fittings from Table 17	Equivalent length	Liquid recirculation	No.	Saturation Temp., °F	Pipe size, in.
1	Liquid feed from +32°F vessel to +23°F intercooler	900	20	50	70	1:1	10	+23	4
2	Liquid feed from intercooler to low-pressure receiver	490	30	50	80	1:1	10	−31	3
3	−31°F pumped liquid supply to plate freezers and cold store	391	100	30	130	4:1	14	−31	4
4	−31°F wet return from LT load	391	100	50	150	4:1	18	−31	6
5	Booster dry suction	391	40	30	70	1:1	15	−31	4
6	+23°F pumped liquid supply to high-temp. loads	233	100	50	150	2:1	16	+32	3
7	+23°F wet return	233	100	50	150	2:1	18	+23	3
8	+23°F high-stage compressor suction	723	40	30	70	1:1	16	+23	3 ½
9	+32°F process area refrigeration liquid supply	244	200	50	250	1:1	10	+32	2 ½
10	+32°F process area dry suction	244	200	50	250	1:1	15	+32	2 ½
11	Parallel compression suction header	409	100	50	150	1:1	15	+32	3

LIQUID PUMP SUCTION LINES

Pearson (2005) makes a compelling case for a 2:1 LR rate in terms of air-cooling evaporator efficiency enhanced by high mass velocities in long evaporator circuits at a moderate pressure drop. Pearson (2005) also presents the results of the excellent performance of a CO2 plate freezer with a recirculation rate of 4:1.

As in the case of beef chilling, an LR ratio is chosen such that peak heat loads may exceed average heat loads by as much as 75%. In such a case a 2:1 LR rate still delivers a wet evaporator exit vapor at a quality of 88%.

With the current development of evaporator exit vapor quality sensing methods, regulating liquid supply to evaporators over a widely fluctuating capacity range generated in process refrigeration systems will be possible.

Cavitation is always a risk in the suction lines of refrigerant circulating pumps. So it is recommended that CO2 liquid velocities in pump suction lines do not

Table 9. Pipe size equivalent length factors for pipe system fittings
(equivalent pipe length = NAS fitting size in ft x equivalent pipe length factor)

Fittings	Equivalent pipe length factor
Threaded bends	
90° elbow, r/d = 1	30
45° elbow, r/d = 1	16
Welded bends	
90° elbows, sharp bend	55
90° elbows, r/d = 1	19
90° elbows, r/d = 1.5	13
90° elbows, r/d = 2	11
45° elbows, sharp bend	18
45° elbows, r/d = 1	14
45° elbows, r/d = 1.5	9.4
Threaded tees	
tee, straight through	20
tee, through branch	60
Welded tees	
tees, square, straight through	0
tees, square, through branch	70
tees, radiused, straight through	10
tees, radiused, through branch	57
Valves/strainers	
globe valves, full open	320
gate valves, full open	7.5
ball valves, full bore	2.6
ball valves, reduced bore	25
plug valves, 2-way	17
plug valves, 3-way, straight through	29
plug valves, 3-way, through branch	84
diaphragm valves, weir type	160
butterfly valves	37
lift check valves	560
swing check valves	95
wafer disk check valves	420
Y-strainers, clean	250

Note: r/d = radius of the elbow / diameter of pipe

exceed 80 ft/ min ±10%.

The pump capacities may be obtained from Tables 8–12 for the relevant LR rate; in this case, Table 10 for the chiller pump and Table 12 for the 4:1 LR ratio to the plate freezers and cold store. See Table 21 for the liquid pump suction sizes.

EQUIVALENT HIGH-STAGE COP

In conventional two-stage ammonia systems used in meat packing plants (MPPs), no parallel compression (PC) is present and the process area cooling (PAC) is provided by the high-stage (HS) compressor. Arguably then, the effective high-stage capacity in this case is equal to the high-stage capacity plus the process area cooling refrigeration, i.e., 636 TR + 244 TR = 880 TR. See Item 4 in Table 22.

The equivalent power consumption includes the PC energy consumption given a total of 233 + 158 + 546 BHP = 937 BHP. Thus the BHP/TR equals 937 BHP ÷ 880 TR = 1.065. Thus the equivalent COP is 4.7162 ÷ 1.065 = 4.43. This compares satisfactorily with a COP of 3.9 for ammonia at 17.6°F SST and 95°F SCT. See Figures 19 and 20. In Figure 20 the CO2 COP is shown much higher at about 5.87 but the reality is that the energy consumed in parallel compression, i.e., 158 BHP in Table 2, is an energy subsidy to improve the COP of the high-stage compressor, thus a real COP of 4.93 applies in this case.

OIL RECOVERY

Ultimately all oil entering the system will end up in the low-pressure receiver (LPR). Unlike in the case of ammonia, oil needs to be distilled out. To reduce the energy input and resulting heat load from such oil distilling processes, the heat source for oil distilling is provided by 32°F liquid flowing the 32°F suction trap (20) to the 23°F high-stage accumulator/intercooler (Item 22 in Figure 18). Oil is then recycled to a head pressure tank for reuse in the compressors. The ultimate degree of oil recovery should be a minimum as the benefit of the liquid subcooling only partially offsets the energy consumption of the booster and the associated high-stage load.

That the oil separation practices applied in the compressor discharges be of the highest performance and best practice is important.

PRESSURE VESSEL DESIGN

Bent Wiencke has written the definitive conclusive manual on the sizing and design of gravity separators for industrial refrigeration (2010, 2011). His clear conclusion is that the separation velocities for CO2 are considerably lower than those for ammonia.

Consider a vapor stream in which liquid droplets are entrained. Several forces act on the suspended liquid droplets as follows:

1. Gravity pulls the droplet down.
2. Buoyancy supports the droplet.
3. The drag force exerted by the vapor stream prevents the droplet from dropping.
4. The friction force resists a liquid droplet falling down from an upward vapor velocity.

See also Stoecker (1960) for an excellent paper on this matter.

In this particular case there are three compression cycles:

Table 10. Pumped CO2 liquid mains capacities for stainless steel grade TP304L pipes (ASTM A312, Seamless), overfeed rate 1:1

Pipe size		Pipe schedule	Pipe wall thickness, in.	Pipe ID, in.	Max. working pressure psi	Velocity in pipe, ft/second	Head loss, ft/100ft	Pipe cross section, in.^{2}	Flow in pipe, U.S. gpm	Enthalpy gain, BTU/U.S. gallon					
DN Metric	National Pipe Size									41°F	32°F	14°F	− 22°F	− 40°F	− 58°F
										704	776	912	1,163	1,278	1,400
										Evaporator capacity, TR					
10	1/8	10S	0.09	0.50	5,428	2.30	6.6	0.19	1.27	4.43	4.88	5.79	7.38	8.07	8.86
15	½	10S	0.11	0.62	5,207	2.62	6.6	0.31	2.53	8.92	9.83	11.64	14.82	16.19	17.72
20	¾	10S	0.11	0.83	3,016	2.95	6.6	0.54	5.07	17.84	19.65	23.29	29.54	32.38	35.50
25	1	10S	0.13	1.05	3,177	3.28	6.6	0.87	8.87	31.24	34.36	40.61	51.97	56.52	62.20
32	1 ¼	10S	0.14	1.38	2,471	3.61	6.6	1.49	17.42	60.78	67.02	80.09	102	110	121
40	1 ½	10S	0.15	1.61	2,148	4.27	6.6	2.03	26.93	94.29	103	124	157	171	187
50	2	10S	0.15	2.07	1,706	4.92	6.6	3.35	51.32	181	199	236	300	328	359
65	2 ½	10S	0.20	2.47	1,545	5.58	6.6	4.81	83.95	294	323	385	491	533	584
80	3	10S	0.22	3.07	2,324	6.23	6.6	7.75	150	525	579	691	880	954	1,045
90	3 ½	10S	0.22	3.55	2,118	6.89	6.6	9.92	215	751	827	989	1,259	1,364	1,494
100	4	10S	0.24	4.02	1,956	7.64	6.6	12.71	303	1,063	1,172	1,389	1,757	1,931	2,116
125	5	10S	0.26	5.04	1,721	8.96	6.6	20.00	558	1,903	2,160	2,559	3,239	3,559	3,899
150	6	10S	0.28	6.07	1,559	9.42	6.6	28.99	851	2,989	3,294	3,904	4,941	5,429	5,948
200	8	10S	0.32	8.00	1,368	11.55	6.6	50.07	1,806	6,329	6,975	8,267	10,462	11,496	12,594
250	10	10S	0.37	10.05	1,236	13.65	6.6	78.90	3,358	11,801	12,994	15,413	19,507	21,413	23,458
300	12	10S	0.38	12.02	1,074	15.19	6.6	175.15	5,354	18,745	20,660	24,574	31,101	34,048	37,299

Table 11. Pumped CO2 liquid mains capacities for stainless steel grade TP304L pipes (ASTM A312, seamless), overfeed rate 1.5:1

Pipe size		Pipe schedule	Pipe wall thickness, in.	Pipe ID, in.	Max. working pressure psi	Velocity in pipe, ft/second	Head loss, ft/100ft	Pipe cross section, in.^{2}	Flow in pipe, U.S. gpm	Enthalpy gain, BTU/U.S. gallon					
DN Metric	National Pipe Size									41°F	32°F	14°F	− 22°F	− 40°F	− 58°F
										470	521	608	779	855	934
										Evaporator capacity, TR					
10	1/8	10S	0.09	0.50	5,428	2.30	6.6	0.19	1.27	2.98	4.88	5.79	7.38	8.07	8.86
15	½	10S	0.11	0.62	5,207	2.62	6.6	0.31	2.53	8.92	9.83	11.64	14.82	16.19	17.72
20	¾	10S	0.11	0.83	3,016	2.95	6.6	0.54	5.07	17.84	19.65	23.29	29.54	32.38	35.50
25	1	10S	0.13	1.05	3,177	3.28	6.6	0.87	8.87	31.24	34.36	40.61	51.97	56.52	62.20
32	1 ¼	10S	0.14	1.38	2,471	3.61	6.6	1.49	17.42	60.78	67.02	80.09	102	110	121
40	1 ½	10S	0.15	1.61	2,148	4.27	6.6	2.03	26.93	94.29	103	124	157	171	187
50	2	10S	0.15	2.07	1,706	4.92	6.6	3.35	51.32	181	199	236	300	328	359
65	2 ½	10S	0.20	2.47	1,545	5.58	6.6	4.81	83.95	294	323	385	491	533	584
80	3	10S	0.22	3.07	2,324	6.23	6.6	7.75	150	351	389	462	586	638	696
90	3 ½	10S	0.22	3.55	2,118	6.89	6.6	9.92	215	502	556	660	838	912	995
100	4	10S	0.24	4.02	1,956	7.64	6.6	12.71	303	711	787	928	1,177	1,291	1,410
125	5	10S	0.26	5.04	1,721	8.96	6.6	20.00	558	1,310	1,450	1,586	2,069	2,379	2,599
150	6	10S	0.28	6.07	1,559	9.42	6.6	28.99	851	1,993	2,196	2,420	3,152	3,620	3,965
200	8	10S	0.32	8.00	1,368	11.55	6.6	50.07	1,806	4,219	4,650	5,123	6,673	7,664	8,396
250	10	10S	0.37	10.05	1,236	13.65	6.6	78.90	3,358	7,880	8,722	9,553	12,440	14,330	15,654
300	12	10S	0.38	12.02	1,074	15.19	6.6	175.15	5,354	12,529	13,868	15,230	19,838	22,762	24,866

Table 12. Pumped CO2 liquid mains capacities for stainless steel grade TP304L pipes (ASTM A312, seamless), overfeed rate 2:1

Pipe size		Pipe schedule	Pipe wall thickness, in.	Pipe ID, in.	Max. working pressure psi	Velocity in pipe, ft/second	Head loss, ft/100ft	Pipe cross section, in.^{2}	Flow in pipe, U.S. gpm	Evaporator capacity, TR					
DN Metric	National Pipe Size									Enthalpy gain, BTU/U.S. gallon					
										41°F	32°F	14°F	−22°F	−40°F	−58°F
										352	388	446	585	639	700
10	1/8	10S	0.09	0.50	5,428	2.30	6.6	0.19	1.27	2.22	2.44	2.90	3.69	4.03	4.43
15	½	10S	0.11	0.62	5,207	2.62	6.6	0.31	2.53	4.46	4.91	5.82	7.41	8.09	8.86
20	¾	10S	0.11	0.83	3,016	2.95	6.6	0.54	5.07	8.92	9.83	11.64	14.82	16.19	17.72
25	1	10S	0.13	1.05	3,177	3.28	6.6	0.87	8.87	15.59	17.18	20.36	25.93	28.31	30.96
32	1 ¼	10S	0.14	1.38	2,471	3.61	6.6	1.49	17.42	30.39	33.51	40.04	50.84	55.10	60.49
40	1 ½	10S	0.15	1.61	2,148	4.27	6.6	2.03	26.93	47.14	51.69	61.91	78.67	85.48	93.44
50	2	10S	0.15	2.07	1,706	4.92	6.6	3.35	51.32	90.31	99.40	118	150	164	179
65	2 ½	10S	0.20	2.47	1,545	5.58	6.6	4.81	83.95	147	162	193	245	266	292
80	3	10S	0.22	3.07	2,324	6.23	6.6	7.75	150	263	289	345	440	477	523
90	3 ½	10S	0.22	3.55	2,118	6.89	6.6	9.92	215	375	414	494	630	682	747
100	4	10S	0.24	4.02	1,956	7.64	6.6	12.71	303	532	586	694	879	966	1,058
125	5	10S	0.26	5.04	1,721	8.96	6.6	20.00	558	951	1,080	1,280	1,619	1,780	1,949
150	6	10S	0.28	6.07	1,559	9.42	6.6	28.99	851	1,495	1,647	1,952	2,471	2,715	2,974
200	8	10S	0.32	8.00	1,368	11.55	6.6	50.07	1,806	3,165	3,488	4,133	5,231	5,748	6,297
250	10	10S	0.37	10.05	1,236	13.65	6.6	78.90	3,358	5,900	6,497	7,707	9,754	10,707	11,729
300	12	10S	0.38	12.02	1,074	15.19	6.6	175.15	5,354	9,373	10,330	12,287	15,551	17,024	18,650

Table 13. Pumped CO2 liquid mains capacities for stainless steel grade TP304L pipes (ASTM A312, seamless), overfeed rate 3:1

Pipe size		Pipe schedule	Pipe wall thickness, in.	Pipe ID, in.	Max. working pressure psi	Velocity in pipe, ft/second	Head loss, ft/100ft	Pipe cross section, in.^{2}	Flow in pipe, U.S. gpm	Enthalpy gain, BTU/U.S. gallon					
DN Metric	National Pipe Size									41°F	32°F	14°F	− 22°F	− 40°F	− 58°F
										237	262	304	373	427	467
										Evaporator capacity, TR					
10	1/8	10S	0.09	0.50	5,428	2.30	6.6	0.19	1.27	1.51	1.65	1.96	2.47	2.70	2.95
15	½	10S	0.11	0.62	5,207	2.62	6.6	0.31	2.53	2.98	3.29	3.89	4.94	5.42	3.07
20	¾	10S	0.11	0.83	3,016	2.95	6.6	0.54	5.07	5.96	6.59	7.78	9.85	10.82	11.81
25	1	10S	0.13	1.05	3,177	3.28	6.6	0.87	8.87	10.42	11.53	13.60	17.32	18.89	20.73
32	1 ¼	10S	0.14	1.38	2,471	3.61	6.6	1.49	17.42	20.31	22.44	26.70	34.08	36.92	40.33
40	1 ½	10S	0.15	1.61	2,148	4.27	6.6	2.03	26.93	31.52	34.93	41.46	52.54	57.08	62.48
50	2	10S	0.15	2.07	1,706	4.92	6.6	3.35	51.32	60.21	66.74	78.67	99.97	110	120
65	2 ½	10S	0.20	2.47	1,545	5.58	6.6	4.81	83.95	98.26	108	129	163	178	195
80	3	10S	0.22	3.07	2,324	6.23	6.6	7.75	150	176	194	231	293	319	348
90	3 ½	10S	0.22	3.55	2,118	6.89	6.6	9.92	215	251	278	330	419	456	498
100	4	10S	0.24	4.02	1,956	7.64	6.6	12.71	303	355	393	464	589	646	705
125	5	10S	0.26	5.04	1,721	8.96	6.6	20.00	558	655	725	793	1,035	1,190	1,300
150	6	10S	0.28	6.07	1,559	9.42	6.6	28.99	851	997	1,098	1,210	1,576	1,810	1,983
200	8	10S	0.32	8.00	1,368	11.55	6.6	50.07	1,806	2,110	2,325	2,562	3,337	3,832	4,198
250	10	10S	0.37	10.05	1,236	13.65	6.6	78.90	3,358	3,940	4,361	4,777	6,220	7,165	7,827
300	12	10S	0.38	12.02	1,074	15.19	6.6	175.15	5,354	6,264	6,934	7,615	9,919	11,381	12,433

Table 14. Pumped CO2 liquid mains capacities for stainless steel grade TP304L pipes (ASTM A312, seamless), overfeed rate 4:1

Pipe size		Pipe schedule	Pipe wall thickness, in.	Pipe ID, in.	Max. working pressure psi	Velocity in pipe, ft/second	Head loss, ft/100ft	Pipe cross section, in.^{2}	Flow in pipe, U.S. gpm	Enthalpy gain, BTU/U.S. gallon					
DN Metric	National Pipe Size									41°F	32°F	14°F	−22°F	−40°F	−58°F
										176	194	228	291	320	348
										Evaporator capacity, TR					
10	1/8	10S	0.09	0.50	5,428	2.30	6.6	0.19	1.27	1.11	1.22	1.45	1.85	2.02	2.22
15	½	10S	0.11	0.62	5,207	2.62	6.6	0.31	2.53	2.24	2.47	2.93	3.72	4.06	4.43
20	¾	10S	0.11	0.83	3,016	2.95	6.6	0.54	5.07	4.46	4.91	5.82	7.41	8.09	8.86
25	1	10S	0.13	1.05	3,177	3.28	6.6	0.87	8.87	7.81	8.61	10.20	12.98	14.17	15.48
32	1 ¼	10S	0.14	1.38	2,471	3.61	6.6	1.49	17.42	15.19	16.76	20.02	25.42	27.55	30.39
40	1 ½	10S	0.15	1.61	2,148	4.27	6.6	2.03	26.93	23.57	25.84	30.96	39.48	42.88	46.86
50	2	10S	0.15	2.07	1,706	4.92	6.6	3.35	51.32	45.16	49.70	59.07	74.98	82.08	89.74
65	2 ½	10S	0.20	2.47	1,545	5.58	6.6	4.81	83.95	73.56	80.94	96.28	123	133	146
80	3	10S	0.22	3.07	2,324	6.23	6.6	7.75	150	131	145	173	220	239	261
90	3 ½	10S	0.22	3.55	2,118	6.89	6.6	9.92	215	188	207	247	315	341	374
100	4	10S	0.24	4.02	1,956	7.64	6.6	12.71	303	266	293	347	439	483	529
125	5	10S	0.26	5.04	1,721	8.96	6.6	20.00	558	476	540	640	810	890	975
150	6	10S	0.28	6.07	1,559	9.42	6.6	28.99	851	747	824	976	1,235	1,358	1,487
200	8	10S	0.32	8.00	1,368	11.55	6.6	50.07	1,806	1,582	1,744	2,067	2,616	2,874	3,148
250	10	10S	0.37	10.05	1,236	13.65	6.6	78.90	3,358	2,950	3,248	3,853	4,877	5,353	5,865
300	12	10S	0.38	12.02	1,074	15.19	6.6	175.15	5,354	4,686	5,165	6,143	7,775	8,512	9,325

Table 15. CO2 wet return piping for stainless steel grade TP304L pipes (ASTM A312, seamless schedule 40), recirculation rate 1:1

Pipe Details		CO_2 Saturated Suction Temperature, °F – Capacities in TR and Vapor Velocity in ft/s											
DN	NPS	−58°F		−40°F		−22°F		+14°F		+32°F		+41°F	
		TR	ft/s(1)	TR	ft/s(1)	TR	ft/s(1)	TR	ft/s(1)	TR	ft/s(1)	TR	ft/s(1)
10	3/8 in.	1.0	16.2	1.4	15.8	1.9	15.6	2.97	15.136	3.54	14.8	3.8	14.4
15	½ in.	2.0	18.9	2.7	18.9	3.5	18.6	5.61	17.888	6.69	17.2	7.2	16.9
20	¾ in.	4.3	23.0	5.9	23.0	7.7	22.7	12.12	21.672	14.46	21.3	15.5	20.6
25	1 in.	8.1	27.5	11.1	27.2	14.6	26.8	23.07	25.8	27.54	25.1	29.4	24.4
32	1 ¼ in.	17.0	33.4	23.4	33.0	30.6	32.7	48.6	31.6	57.9	30.6	62.1	29.9
40	1 ½ in.	26.1	37.5	35.7	37.2	46.8	36.5	74.4	35.4	88.2	34.1	94.5	33.4
50	2 in.	51.3	44.7	70.5	44.4	92.1	43.3	146	42.0	173	40.6	186	39.9
65	2 ½ in.	83.1	50.6	114	50.2	150	49.5	236	47.8	282	46.4	301	45.4
80	3 in.	149	59.2	205	58.5	269	57.4	425	55.7	507	54.0	544	53.0
90	3 ½ in.	222	65.7	305	65.4	401	64.0	633	61.9	754	60.2	808	58.8
100	4 in.	314	71.9	432	71.6	564	69.8	895	67.8	1,061	65.7	1,137	64.3
125	5 in.	580	84.6	793	83.6	1,041	82.2	1,653	79.8	1,959	77.1	2,100	75.7
150	6 in.	955	96.3	1,306	95.3	1,714	93.6	2,721	90.8	3,225	88.1	3,457	86.3
200	8 in.	2,007	117	2,759	116	3,603	114	5,720	110	6,813	107	7,304	105
250	10 in.	3,722	138	5,119	137	6,708	135	10,599	130	12,599	126	13,518	123
300	12 in.	6,077	157	8,358	156	10,898	152	16,703	148	20,553	143	22,052	141

Table 15. CO_2 wet return piping for stainless steel grade TP304L pipes (ASTM A312, seamless schedule 40), recirculation rate 1:1

Pressure drop corresponds to 1°F ΔT/200 ft equivalent pipe length.

Notes: (1) ft/s = feet/second

(2) Capacities are based on a pressure drop of 1°F per 100 ft in schedule 40 pipe

(3) The pressure drops must be in units of pressure, not temperature

(4) To calculate multipliers for other pressure drops, use the expression multiplier = 0.535 (Pearson 1996)

Table 16. CO2 wet return piping for stainless steel grade TP304L pipes (ASTM A312, seamless schedule 40), recirculation rate

Pipe Details		CO_2 Saturated Suction Temperature, °F – Capacities in TR and Vapor Velocity in ft/s											
DN	NPS	−58°F		−40°F		−22°F		+14°F		+32°F		+41°F	
		TR	ft/s(1)	TR	ft/s(1)	TR	ft/s(1)	TR	ft/s(1)	TR	ft/s(1)	TR	ft/s(1)
10	3/8 in.	0.6	10.0	0.9	10.0	1.1	10.0	1.8	10.0	2.1	9.6	2.3	9.6
15	½ in.	1.2	12.0	1.6	12.0	2.1	11.7	3.4	11.7	4.1	11.4	4.4	11.4
20	¾ in.	2.6	14.4	3.5	14.4	4.6	14.4	7.3	14.1	8.8	14.1	9.4	13.8
25	1 in.	4.8	17.2	6.7	17.2	8.7	17.2	13.9	16.9	16.7	16.5	17.9	16.5
32	1 ¼ in.	10.2	21.0	14.0	21.0	18.3	20.6	29.3	20.6	35.1	20.3	37.8	20.0
40	1 ½ in.	15.6	23.4	21.3	23.4	28.2	23.4	44.7	23.0	53.4	22.7	57.6	22.4
50	2 in.	30.6	27.9	42.0	27.9	55.2	27.5	87.9	27.5	105	27.2	113	26.8
65	2 ½ in.	49.5	31.6	68.1	31.6	89.4	31.3	143	31.3	170	30.6	184	30.3
80	3 in.	89.4	37.2	123	37.2	161	36.8	257	36.5	308	35.8	331	35.4
90	3 ½ in.	133	41.3	182	41.3	240	40.9	381	40.2	456	39.9	491	39.6
100	4 in.	188	45.1	258	45.1	339	44.7	539	44.4	645	43.7	692	43.0
125	5 in.	347	53.0	474	53.0	624	52.3	995	51.9	1,191	51.3	1,277	50.6
150	6 in.	570	60.2	785	60.2	1,029	59.9	1,638	59.2	1,961	58.5	2,102	57.4
200	8 in.	1,200	73.3	1,649	73.6	2,164	72.6	3,444	71.9	4,122	70.9	4,441	70.2
250	10 in.	2,225	86.3	3,059	86.3	4,009	85.3	6,380	84.6	7,660	83.6	8,219	82.6
300	12 in.	3,632	98.4	4,996	98.4	6,547	97.4	10,440	96.3	12,497	95.3	13,408	93.9

Table 16. CO_2 wet return piping for stainless steel grade TP304L pipes (ASTM A312, seamless schedule 40), recirculation rate 1.5:1

Pressure drop corresponds to 1°F ΔT/200 ft equivalent pipe length.

Notes: (1) ft/s = feet/second
(2) Capacities are based on a pressure drop of 1°F per 100 ft in schedule 40 pipe
(3) The pressure drops must be in units of pressure, not temperature
(4) To calculate multipliers for other pressure drops, use the expression multiplier = 0.535 (Pearson 1996)

Table 17. CO2 wet return piping for stainless steel grade TP304L pipes (ASTM A312, seamless schedule 40), recirculation rate 2:1

Pipe Details		CO_2 Saturated Suction Temperature, °F – Capacities in TR and Vapor Velocity in ft/s											
DN	NPS	−58°F		−40°F		−22°F		+14°F		+32°F		+41°F	
		TR	ft/s(1)	TR	ft/s(1)	TR	ft/s(1)	TR	ft/s(1)	TR	ft/s(1)	TR	ft/s(1)
10	3/8 in.	0.6	8.9	0.8	8.9	1.0	8.9	1.6	8.9	1.9	8.9	2.0	8.6
15	½ in.	1.0	10.7	1.4	10.7	1.9	10.7	2.9	10.7	3.5	10.3	3.8	10.3
20	¾ in.	2.3	13.1	3.1	13.4	4.0	13.1	6.4	13.1	7.6	12.7	8.1	12.7
25	1 in.	4.3	15.5	5.9	15.5	7.7	15.5	12.1	15.5	14.4	15.1	15.5	14.8
32	1 ¼ in.	8.9	18.9	12.3	18.9	16.1	18.9	25.5	18.6	30.3	18.2	327.0	18.2
40	1 ½ in.	13.7	21.3	18.8	21.3	24.6	21.0	39.0	21.0	46.2	20.6	49.8	20.3
50	2 in.	28.4	25.8	39	25.8	51	25.5	80.7	25.1	96	24.8	103	24.4
65	2 ½ in.	43.5	28.6	60	28.9	78.3	28.6	124	28.2	148	27.9	158	27.5
80	3 in.	78.6	33.7	108	33.7	141	33.4	224	33.0	266	32.7	285	32.0
90	3 ½ in.	117	37.2	160	37.2	209	36.8	332	36.5	395	36.1	425	35.8
100	4 in.	165	40.9	226	40.9	296	40.6	469	40.2	558	39.6	599	39.2
125	5 in.	304	47.8	418	47.8	547	47.5	866	47.1	1,031	46.4	1,106	46.1
150	6 in.	502	54.7	688	54.7	900	54.4	1,425	53.7	1,697	53.0	1,814	52.3
200	8 in.	1,056	66.4	1,445	66.4	1,893	66.0	2,999	65.4	3,570	64.3	3,822	63.6
250	10 in.	1,955	78.1	2,680	78.1	3,521	77.7	5,577	77.1	6,606	75.7	7,080	74.6
300	12 in.	3,182	88.8	4,363	88.8	5,728	88.1	9,072	87.4	10,800	86.0	11,006	85.3

Table 17. CO_2 wet return piping for stainless steel grade TP304L pipes (ASTM A312, seamless schedule 40), recirculation rate 2:1

Pressure drop corresponds to 1°F ΔT/200 ft equivalent pipe length.

Notes: (1) ft/s = feet/second

(2) Capacities are based on a pressure drop of 1°F per 100 ft in schedule 40 pipe

(3) The pressure drops must be in units of pressure, not temperature

(4) To calculate multipliers for other pressure drops, use the expression multiplier = 0.535 (Pearson 1996)

Table 18. CO2 wet return piping for stainless steel grade TP304L pipes (ASTM A312, seamless schedule 40), recirculation rate 4:1

Pipe Details		CO_2 Saturated Suction Temperature, °F – Capacities in TR and Vapor Velocity in ft/s					
DN	NPS	−58°F		−40°F		−22°F	
		TR	ft/s(1)	TR	ft/s(1)	TR	ft/s(1)
40	1 ½ in.	9.8	16.5	13.4	16.5	17.4	16.2
50	2 in.	19.4	19.6	26.4	19.6	34.2	19.3
65	2 ½ in.	31.5	22.4	42.9	22.4	55.5	22.0
80	3 in.	56.7	26.1	77.1	26.1	99.9	25.8
90	3 ½ in.	84.3	28.9	115	28.9	149	28.6
100	4 in.	119	31.6	161	31.6	210	31.3
125	5 in.	219	37.2	299	37.2	388	36.8
150	6 in.	360	42.3	492	42.3	639	42.0
200	8 in.	758	51.3	1,034	51.6	1,343	50.9
250	10 in.	1,408	60.5	1,921	60.9	2,494	60.2
300	12 in.	2,280	68.8	3,134	69.1	4,069	68.5

Table 18. CO_2 wet return piping for stainless steel grade TP304L pipes (ASTM A312, seamless schedule 40), recirculation rate 4:1

Pressure drop corresponds to 1°F ΔT/200 ft equivalent pipe length.

Notes: (1) ft/s = feet/second
(2) Capacities are based on a pressure drop of 1°F per 100 ft in schedule 40 pipe
(3) The pressure drops must be in units of pressure, not temperature
(4) To calculate multipliers for other pressure drops, use the expression multiplier = 0.535 (Pearson 1996)

- AC/parallel compression for a CO2 DX system at an evaporating temperature of 32°F.
- High-stage compressors serving as the compressors for the chilling loads and the second stage for the booster compressors at an evaporating temperature of +23°F.

  Booster compressors to provide capacity for the plate freezers and cold store at an evaporating temperature of –31°F.

In Table 23 separation velocities of 25, 25, 30, and 40 ft/min were selected for the 32°F AC compressor suction trap, the +23°F accumulator/intercooler, the low-pressure receiver, and the oil still separator. The CO2 liquid-to-vapor density ratios for +32, +23, and –31°F are 9.5, 11.5, and 35:1 respectively. The NH3 liquid-to-vapor density ratios for the same temperatures are 184, 233, and 531:1. This shows that separating liquid droplets from an ammonia vapor stream is much easier than from a CO2 vapor stream.

In the case of the LPR the separation velocity is not relevant as the LPR acts as the system receiver as well as the freezer accumulator. Based on that we advocate the use of all liquid separation techniques in a design, i.e., impingement, change of direction, and centrifugal.

BENEFITS AND DISADVANTAGES OF WATER HEATING BY CONDENSING CO2

Using the heat rejection from high-stage and AC parallel compressors has significant advantages in meat production facilities like beef, pork, and poultry plants, which consume large volumes of hot water for processes like sterilization and scalding prior to defeathering of chickens and dehairing of hogs. Hospitals and hotels also use large volumes of hot water and would benefit from CO2 AC for cooling and heating and hot water production (Visser 2014c, 2015b, 2016).

The advantages are

- Significant fuel energy cost reduction for hot water production.
- Significant reduction in condenser water consumption, including water treatment chemicals and disposal of bleed water to sewer or effluent treatment system.
- Reduction in CO2 global warming emissions (GWE) due to reduced gas consumption.
- High degree of liquid subcooling by preheating water in a heat exchanger in the liquid feed brine to the DX suction trap.
- Reduction in booster discharge temperature to the intercooler by preheating water and superheating the suction vapor to the AC/parallel compressors to achieve a high enough discharge temperature for water heating. This reduces the booster discharge heat load by 87 kWR from 490 TR to 403 TR. This represents a reduction of 12% in the total high-stage heat load of 723 TR to 636 TR.

The disadvantages are

Table 19. Tabulation of parameters for design purposes of CO2 refrigeration piping, pressure vessels

Parameter			Saturated Suction Temperature, °F		
No	Description	Unit	32	23	− 31
1	System type		DX	LR	LR
2	Suction super heat	°F	9	0	0
3	Suction gas temperature	°F	41	23	− 31
4	Liquid feed temperature	°F	68	23	23
5	Liquid enthalpy	BTU/lb	61.5	32.3	32.3
6	Vapor enthalpy	BTU/lb	136.8	137.9	139.1
7	Enthalpy rise in evaporator	BTU/lb	75.3	105.6	106.8
8	Liquid density	lbm/ft^3	57.9	59.7	69.7
9	Vapor specific volume	lt^3/lbm	0.167	0.192	0.613
10	Total capacity	TR	389	636	391
11	Rate of heat removed/ evaporation	BTU/min	200	200	200
12	Total heat removed	BTU/min	77,800	127,200	78,200
13	Evaporation rate, 12 ÷ 7	lbm/min	1,033	1,205	732
14	Evaporator capacity	TR	244	233	391
15	Booster discharge	TR	-	403	-
16	Parallel flash gas compressor	TR	145	-	-
17	Total compressor capacity	TR	389	636	391
18	Vapor volume generated, 13 ´ 9	cfm	173	231	449
19	Volumetric efficiency, assumed	%	85	85	85
20	Estimated CO_2 compressor swept volume	cfm	204	272	528
21	Ammonia compressor swept volume for equal capacity @ −33°F/+29°F/+86°F (1)	cfm	956	1,783	4,018
22	NH_3 to CO_2 swept volume ratio		4.69	6.56	7.61

Table 19. Tabulation of parameters for design purposes of CO_2 refrigeration piping, pressure vessels
(1) Based on a 750 cfm reciprocating compressor

- The need for a large-capacity hot water storage tank at a temperature of 150°F.
- Cost of high-pressure CO2-to-water heat exchangers. This cost would be offset by the cost of a gas-heated hot water plant.
- The need for a controlled AC and high-stage CO2 compressor discharge temperature to a minimum of 160°F to achieve an exit water temperature of 150°F. This requires the suction superheat be lifted to approximately 15°F in the case of both the high-stage and AC compressors. The result of the increased superheat is a reduction in the compressor cooling COP of 3% and 1%, thus a small increase in electrical energy consumption of the CO2 compressor occurs.

Table 24 and Figure 21 show the performance of a high-stage CO2 compressor as a water-heating heat pump in terms of the variation in evaporator and compressor capacities, COPs, and discharge temperatures with increasing suction super heat. Table 25 and Figure 22 show the performance of an AC/parallel CO2 compressor.

An advantage of CO2 compressors is that at 86°F saturated condensing temperature 68% of the heat rejected is sensible heat with only the remaining 32% of the heat as latent heat. See Figure 23.

In Table 26 the four types of heat recovery are evaluated. Note that the heat rejection from the booster discharge reduces by 51 TR or 8%.

The calculated total heat generated is 145.6 therms per hour, i.e. say availability 140 therms/hour at design conditions. This will vary with load, and compressor superheat level and rate of water flow need to be tightly controlled. See Figure 21.

As shown in Table 25, at design conditions sufficient heat is available to heat 320 U.S. gallons of water per minute from the mains water temperature of 59°F to 150°F in four stages as shown in Figure 24. This process not only saves considerable amounts of gas, but also evaporative condenser water.

Table 21. Liquid pump suction line determination

Liquid pump suction line	LR rate	Capacity, TR	Table	Pump flow, U.S. gpm			Suction pipe vel. ft/min ± 10%	Pipe size, in.
				To evaporators	To bypass 20%	Total pump capacity		
1. Chiller liquid pump	2	233	10	206	42	248	80	8
2. Freezer liquid pump	4	391	12	256	51	307	80	10

Table 22. Tabulation of power consumption at design conditions

Liquid pump suction line	LR rate	Capacity, TR	Table	Pump flow, U.S. gpm			Suction pipe vel. ft/min ± 10%	Pipe size, in.
				To evaporators	To bypass 20%	Total pump capacity		
1. Chiller liquid pump	2	233	10	206	42	248	80	8
2. Freezer liquid pump	4	391	12	256	51	307	80	10

Table 27 summarizes the annual reductions in gas and water consumption.

SUMMARY OF SOUND INDUSTRIAL CO2 REFRIGERATION SYSTEM DESIGN BASED ON AMMONIA SYSTEM DESIGN PRACTICES

In the previous sections an effort was made to explain that applying CO2 in industrial and most other refrigeration applications has a great deal of merit and is not all that different from designing an industrial ammonia refrigeration system.

The following steps are involved:

1. Determine various heat loads in the system.
2. Select a refrigerant supply system: DX, flooded (FL), or LR.
3. Select evaporating temperatures for various sections like process area cooling with glycol brine; process product chilling, e.g., hot boxes; and process product freezing such as spiral, blast, and plate freezers.
4. Design evaporators in house or select suitable air coolers from manufacturers' data. Generally CO2 evaporators have considerably less surface area than equivalent capacity ammonia evaporators with equivalent circuit pressure drop expressed in boiling point temperature reduction along the refrigerant circuit. In all applications the suction take-off from the evaporator should be from the lowest point suction header in the evaporator.
5. Select defrosting method. Both hot gas and electrical defrost are suitable, as is warm glycol generated by heat recovery from the booster or

Table 23. Summary of pressure vessel design

Parameter			Vessel Functions and Operating Temperature						
No	Description	Unit	CO_2 liquid receiver + 86°F	+ 32°F expansion vessel / suction trap	+ 41°F expansion vessel for 32°F DX evaporator liquid	+ 23°F accumulator/ intercooler	− 31°F accumulator / low-pressure receiver	Oil still collection vessel − 31°F/41°F	Oil reservoir 250 gallons
1	Number on schematic		19	20	21	22	23	34	35
2	Infeed flow rate	lb/min	2,238	1,690	648	1,205	732	NA	NA
3	CO_2 temperature @ entry	°F	86	32	41	23	− 31	− 31	
4	CO_2 liquid density @ entry	1b/ft³	37.04	57.9	55.9	59.7	68.45	NA	NA
5	Supply time in operating charge	s	60	60	60	60	NA	NA	NA
6	Operating charge, volume	ft³	60.42	29.2	11.6	20.18	10.7	3.34	33.4
7	Surge volume, 50% of operating	ft³	30.21	14.6	5.8	10.09	5.9	1.67	16.7
8	Connected evaporator volume	ft³	-	10	-	98.9	2,207	5	0
9	Total vessel volume	ft³	90.63	53.8	17.4	129.2	2,224	10.0	50.1
10	Vapor flow to compressor	cfm	-	173	-	231	449	42.5	NA
11	Safe vapor velocity	ft/min	-	25	NA	25	30	40	NA
12	Minimum vessel X section	ft²	-	6.92	2.0	9.24	14.97	1.06	4.91
13	Vessel diameter	in.	42	36	21	42	2 x 96	18	30
14	Vessel straight shell length SE ends	ft	8	6 ft 6 in.	6 ft 6 in.	12 ft 6 in.	20	6	10
15	Vessel attitude	Hor/ Vert	Vertical	Vertical	Vertical	Vertical	Vertical	Vertical	Vertical
16	Vessel material		Boiler plate	Boiler plate	Boiler plate	LT or stainless steel	LT or stainless steel	LT or stainless steel	LT or stainless steel
17	Operating pressure	psi g	1,032	491	561	427	160	561	561
18	Design pressure	psi g	1,500	750	750	750	600	750	750
19	Test pressure	psi g	2,250	1,125	1,125	1,125	900	1,125	1,125

high-stage compressors. The glycol tube circuit would ideally comprise one glycol tube for every four refrigerant tubes. Drain tray heaters are required in all cases, except where water defrost is applied.

6. Lay the refrigerating system out on the plan of the facility.
7. Size the liquid supply piping for the various DX and/or LR operations.

a. Select DX liquid piping at an LR ratio of 1:1 in Table 8.

b. In the case of highly variable refrigeration loads such as batch loaded hot boxes, the peak heat load can exceed the average heat load by 50 to 75%. Select liquid piping at a LR ratio of 1.5 to 2:1 from Tables 9 and 10.

c. In the case of steady process freezing and cold storage loads select piping at LR ratios of 1:1 to 1.5:1 from Tables 8 and 9.

d. Plate freezers may require a higher circulation rate depending on the plate construction, circuit length, and heat flux. Circulation rates of 2:1 to 4:1 are to be expected. See Tables 10–12. Plate freezer CO2 LR rates are considerably lower than those used for LR ammonia refrig-

Table 24. CO2 compressor performance at 86°F saturated condensing, +23°F saturated suction, and +23°F gas cooler exit

Suction Super Heat °F	Capacity, TR		Power Consumption BHP	Compressor COP		Evaporator COP		Discharge Temp. °F
	Evap	Comp		Raw	Net	Raw	Net	
9	147	151	39.41	5.69	5.12	5.56	5.0	163
18	140	148.5	39.41	5.59	5.03	5.29	4.76	175
27	135	146	39.41	5.5	4.95	5.1	4.59	187
36	130	144.5	39.41	5.42	4.88	4.91	4.42	199
45	125	143	39.41	5.35	4.82	4.72	4.25	210
54	121	141.5	39.41	5.3	4.77	4.57	4.11	222
63	118	140	39.41	5.24	4.72	4.46	4.01	233

erated plate freezers.

8. When the CO2 flows are known, liquid pumps may be selected using water flow piping design data as the dynamic viscosity of CO2 is about the same as the dynamic viscosity of water at 68°F.

CO2 pump pressures must be considerably higher where back-pressure valves are used to regulate evaporating temperatures because the pressure gradient per degree F for CO2 is much greater than the same for ammonia. For example, the saturation pressures for ammonia at +23°F and +30°F are 37.5 and 48.5 psig respectively, i.e., an 11psi difference. The CO2 saturation pressure are 433 and 498 psig respectively at +23°F and +30°F, which equates to a pressure difference of 65 psi, or nearly six times as high as that for ammonia. A CO2 liquid pump would need to overcome this extra back pressure and thus must be able to perform at a much higher differential pressure. Furthermore, at high evaporating temperatures, CO2 mass flows/TR are quite low compared with ammonia, and thus the energy consumption of a CO2 liquid pump is expected to be much greater than that of an ammonia liquid pump. This is because the energy consumption of a liquid pump is a function of mass flow multiplied by the differential pressure plus static lift and piping friction. Additionally, the energy consumed by a liquid pump is a parasitic heat load in the system, and thus in the case of a CO2 liquid pump this parasitic heat load would be higher leading to higher energy consumption. The next thing to watch is pump cavitation, and we recommend that the available NPSH is at 1.5 times the required NPSH at the pump duty point at the minimum expected operating level, i.e., low-level alarm.

Based on this, DX operations are much preferred. When CO2 evaporator exit quality sensors (EEQS) become available the need for pumped systems may be much lower. EEQS would also assist minimum charge CO2 systems similar to the EEQS's impact on ammonia systems.

It is also recommended that the pump minimum CO2 flow without any consumption in the system be 20% of the system consumption to ensure the CO2 pump does not cavitate at low flow.

Ensuring that the CO2 velocity in the main drop leg from the accumulator does not exceed 80 ft/min at full flow, i.e., 120% of system evaporation rates, is also desirable.

9. Size dry suction and wet return piping corresponding to the liquid feed rates. Determine equivalent length return piping by adding the equivalent length of all bends, tees, valves, and strainers according to Table 17. NPT size is in ft, e.g. 6 in. = 0.5 ft. A good rule of thumb is that CO2 suction piping has about half the diameter of ammonia piping with the same capacity. Like in ammonia systems, suction piping should slope down to the suction traps or pump accumulators to assist oil return.

10. Once total refrigeration capacities are known they are divided into three categories:

a. Process area and AC refrigeration and general AC loads suitable for DX operation at 30–32°F without any defrost requirements. The saturated liquid supply temperature would be 41°F.

b. Refrigeration loads generated by process chilling at operating temperatures of 30–35°F with a liquid supply temperature of 20–23°F. The boosters to the interstage would contribute the other refrigeration load.

c. Refrigeration loads generated by cold stores and process freezers at evaporating temperatures of –30 to –40°F or lower.

11. Compressors and boosters can now be selected as follows:

a. Calculate the CO2 mass flow for the aforementioned three refrigera-

Table 26. Summary of water heating by booster discharge desuperheating, CO2 condenser drain liquid subcooling, and CO2 condensing

Parameter			Heat exchanger location			
No.	Description	Unit	Booster Discharge	Condens. Liquid Drain	Parallel Comp. Discharge	High-Stage Comp. Discharge
1	No. on Schematic		26	27	28	29
2	CO_2 side					
	a. Mass flow	lbs/min	732	2,308	1,105	1,203
	b. Entry temperature	°F	120	86	160	171
	c. Exit temperature	°F	64	68	86	86
	d. Entry enthalpy	Btu/lb	167	82.5	160	164
	e. Leaving enthalpy	Btu/lb	153	61.5	82.5	82.5
	f. Enthalpy reduction	Btu/lb	14	21	77.5	81.7
	g. Heating capacity	MMBtu/h	0.61	2.91	5.14	5.9
	h. Total heat from all sources	MMBtu/h				14.6
	i. Reduction in booster discharge heat to high stage compressor due to					
	i. Water heating					
	ii. Super heating	TR	51	-	-	-
	iii. Total reduction in high-stage load	TR	-	-	36	-
		TR				87
	j. Estimated high-stage load without water heating	TR				723
	k. High-stage load when heating water	TR				636
3	Water side					
	a. Flow rate	U.S. gpm	320	320	149	171
	b. Entry temperature	°F	59	62.8	81	81
	c. Leaving temperature	°F	62.8	81	150	150
	d. Heat load	MMBtu/h	0.61	2.91	5.14	5.9
	e. Total heat to water, all sources	MMBtu/h				14.6

Table 27. Summary of annual reductions in the consumption of gas, water, electrical energy, and GWE

Parameter			Value
No	Description	Unit	
1	No. of cattle/day		1,000
2	Water consumption/head/day	U.S. gallons	693
3	Water/head needing heating	U.S. gallons	346.5
4	Water to be heated/day	U.S. gallons	346,500
5	Initial water temperature	°F	59
6	Final water temperature	°F	150
7	Total heat required/day	MMBtus	263
8	Heat available from water discharge and liquid subcooling	MMBtu/h	3.52
9	Heat available from compressor	MMBtu/h	11.0
10	Total heat available	MMBtu/h	14.6
11	Daily operating time	hours	18
12	Daily hours of operation		24
13	Average load over 24 hours	%	75
14	No. of processing days/year		250
15	Total heat required/year	MMBtus	65,700
16	Gas heater efficiency	%	80
17	Total annual gas consumption required	MMBtus	82,125
18	Gas cost/therm, USA	US$/therm	0.35
19	Gas cost/therm, Australia	AU$/therm	1.25
20	Annual gas savings, USA	US$	287,438
21	Annual gas savings, Australia	AU$	1,026,562
Water savings			
1	Total annual heat rejection	MMBtus	65,700
2	Heat rejected by CO2 compressors	%	75.8
3	Heat rejected by compressors	MMBtus	49,817
4	Water latent heat	BTU/lb	1,060
5	Annual water savings	lb/yr	41,000,000
6	Annual water savings	U.S. gallons	5,640,000
7	Say condenser bleed rate	%	20
8	Annual bleed water loss	U.S. gallons	1,128,000
9	Total annual condenser water saving	U.S. gallons	6,768,000
10	Australian water costs	AU$/kl	0.80
11	Annual water cost savings	$/yr	20,000
Booster discharge cooling benefits			
1	Booster discharge mass flow	lb/min	732
2	Entry temperature into water heater Stage 1	°F	120
3	Leaving temperature from AC/parallel compressor suction super heating	°F	37
4	Entry enthalpy	BTU/lb	167
5	Leaving enthalpy	BTU/lb	143
6	Enthalpy reduction	BTU/lb	24
7	Reduction in heat rejected to high-stage compressor	BTU/min	17,568
8	Heat load/TR	BTU/min	200
9	Reduced heat load to high-stage compressor	TR	87.84
10	Say, heat load reduction	TR	87
11	High-stage COP		5.38
12	Demand saving	BkW	56.9
13	Demand saving	kW	63.0
14	Annual operating days	days/yr	250
15	Daily operating time	hr/day	18
16	Annual operating time	hr/yr	4,500
17	Annual energy savings	kWh/yr	283,500
18	Electrical energy cost	AU$/kWh	0.15
19	Annual electrical energy cost saving	AU$/yr	42,525
20	Estimated electrical energy cost saving in the USA at US$0.10	US$/yr	28,350

Emission reductions			
1	Gas energy saved	MMBtu	82,125
2	Specific CO_2 emissions	lb/MMBtu	137
3	Reduction in annual CO_2 emissions	lb/yr	11,251,125
4	Weight/short tonne	lb	2,000
5	Annual reduction in CO_2 GWE	short tonnes	5,626
6	Annual reduction in electrical energy consumption	kWh/yr	283,500
7	Specific emissions/kWh in the State of Victoria, AU	lbs/kWh	2.65
8	Specific emissions/kWh in the USA	lbs/kWh	1.54
9	Annual reduction in emissions in the State of Victoria, AU	lbs/yr	751,275
10	Annual reductions in emissions, USA	lbs/yr	436,590

tion duties at 32, 23, and –30 to –40 at the respective liquid feed temperatures.

b. Add the economizer load of the high-stage compressor to the AC compressor. This equates to the mass flow to the high-stage compressor multiplied by the enthalpy reduction in the liquid flowing from the liquid receiver or water-cooled liquid subcooler to the first-stage expansion vessel operating at about 40°F saturation temperature.

12. Now that AC/parallel, high, and booster sizes are known, calculate the minimum diameter of suction traps, intercoolers, and low-side suction accumulation using CO2 vapor velocities of about 25–30 ft/min for high-stage vessels and 35–40 ft/min for low-stage vessels. In reality CO2 vessels have about half the diameter of equivalent capacity ammonia vessels.

13. The pilot CO2 liquid receiver should hold 1 minute liquid CO2 supply as operating charge and its volume is two to two and a half times the operating charge volume.

14. Because of the high CO2 pressures, the intercooler is recommended to be made the low-pressure liquid receiver. In such a case, the low-temperature refrigeration would be CO2 DX.

15. In the case of plate freezers the pump accumulator would become the low- pressure receiver because the liquid charge fluctuations in LR plate freezers correspond to about 80% of the internal plate volume.

16. The total system charge needs to include the charge in the evaporative condenser/gas cooler.

17. Using an evaporative condenser for ambient wet bulb design temperatures up to 77°F is quite feasible. This is simply the most important adoption of standard ammonia technology.

18. At higher wet bulb temperatures up to 82.4°F (28°C) an evaporative gas cooler will cool transcritical CO2 to a gas cooler exit temperature of 86

to 87.6°F (30 to 31°C) and at such gas cooler exit temperatures CO_2 refrigeration is quite efficient and compares favorably with ammonia, HFCs, and hydrocarbons applied in hot, humid climates. Please note that the 1% incidence ambient wet bulb design temperature is not exceeded in 98% of the world's climates.

19. Oil separation requires special attention. In the first instance every effort should be made to prevent oil entering the system by using high-efficiency oil separators. Where possible use DX applications for all low-temperature loads. Oil will ultimately arrive at the end of the system. A properly sized suction trap will collect the oil, which may then be drained to an oil drain vessel often passing through a PHX heated by warm liquid from the interstage. This liquid passes first through a coil in the oil drain vessel from where it flows through the PHX. After the PHX the warm liquid flows through a coil in the lower dished end of the vertical suction trap before flowing to the low-temperature evaporators (LTEs). Thus the evaporation of CO_2 entrained in the oil provides a degree of liquid subcooling, and consequently the energy consumption of this system is not adversely affected to any great degree, if at all.

20. In the case of LR systems for low-temperature work, distilling the oil from the system is necessary. This is again accomplished by using warm CO_2 liquid flowing to the Intercooler/high-stage accumulator (IC/HSA) to evaporate a portion of low-temperature liquid from the freezer liquid pump discharge. The subcooling of the liquid flowing to the IC/HSA enhances the COP of the high-stage compressors, but the extra load added to the booster may be quite energy intensive. Therefore, the amount of LT liquid evaporated to remove the oil from the system should be an absolute minimum and be based on the ammonia oil recovery principle that the amount of oil removed from the system must equal the amount of oil added to the system.

21. Flooded evaporators. This is feasible but at this stage the amount of liquid head required above the top of an evaporator to get an effective thermosiphon operating is unknown. CO_2 vapor has a much higher density than NH_3 vapor, and CO_2 liquid is also more dense than NH_3 liquid. So establishing an ammonia thermosiphon is easier. Furthermore, distilling oil from a surge drum on say a CO_2 refrigerated flooded air cooler would be necessary. This is technically possible but a little cumbersome. In the case of hot gas defrost, any CO_2 condensed during defrosting would need to be evaporated before transferring any oil. However, automatically removing any oil from a surge drum after it has been completely pumped down for a defrost may be possible. The author will try a flooded CO_2 system to chill water for office AC fan coil units and will know in about six months how effective the operation is. The standby option is DX on the same CO_2 flooded PHX water chillers.

22. The large potential for heat recovery from CO_2 systems should not be understated in food-processing applications where a lot of one pass hot water is used and in hotels and hospitals.

Hopefully, this summary of how to design a multifunction two-stage sub- or transcritical CO_2 refrigerating system with parallel compression (MF2STC-CO2SPC) is beneficial. Apart from oil recovery, there are very few basic differences between

conventional LR ammonia and MF-2STCCO2SPC systems. CO_2 systems' suction piping and pressure vessels are about half the diameter of those for ammonia. Particularly at elevated evaporating temperatures, CO_2 liquid lines are larger than ammonia liquid lines.

CONCLUSIONS

The inevitable conclusion is that CO_2 is a good refrigerant suitable for use in industrial refrigerating systems if evaporative condensers/gas coolers (EC/GCs) are used, just like evaporative condensers are used as standard equipment in ammonia plants.

In many food-processing industries simultaneous requirements exist for refrigeration and hot water—beef and hog processing, chicken processing, etc.--which is not recyclable. Such single-pass process hot water is heated from mains water temperature to 150°F to 185°F for cleaning and sterilization purposes respectively and is disposed to waste after use.

The high operating pressures of CO_2 are an advantage when using EC/GCs as reducing the condensing temperature to about 12 to 15°F above the ambient wet bulb temperature is possible. This results in low condensing pressure and substantial improvements in COP and thus energy savings.

An AWBDT of 82.4°F is not exceeded in 98% of the world's climates. At this high AWBDT reducing the gas cooler exit temperature to 86 to 87°F is possible, and at such relatively low CO_2 gas cooler exit temperatures the compressor COPs for transcritical operations at 1,100 to 1,200 psi are still quite high and compare reasonably well with the COPs of ammonia high-stage compressors operating at saturated condensing temperatures of 100 to 105°F when using evaporative condensers in high-humidity climates.

Without doubt well-designed CO_2 refrigerating systems using EC/GCs operate efficiently in all climates, which will lower the so-called "CO_2 equator" from the Northern Mediterranean Sea to the geographical equator.

As a rule of thumb, CO_2 vertical pump accumulators and suction traps are about half the diameter of equal capacity ammonia pump accumulators and suction traps. But other requirements for the sizing of such vessels—surge volume, ballast, separation distance—frequently mean that CO_2 and ammonia vessel sizes are not a lot different, and thus operating vapor velocities in CO_2 vessels are quite a bit lower than the maximum permissible vapor velocities to ensure adequate liquid separation from the vapor stream.

CO_2 wet return lines are about half the diameter of ammonia wet return lines of the same capacity with the same boiling point suppression.

At CO_2 evaporating temperatures between 12 and 10°F the pumped liquid and wet return lines are about the same size, which is surprising.

At CO_2 evaporating temperatures of

–20 to –40°F the pumped liquid lines are one to two sizes smaller than the wet return lines. For example at –40°F and a liquid recirculation of 2:1 a 4 in. wet return has a capacity of 226 TR. A 2 ½ in. liquid line has a capacity of 266 TR. A 2 in. liquid line may also be adequate with a rated capacity of 164 TR. The higher the oil consumption, the higher will be the energy requirement to distill the oil from the system. High-quality oil separation is therefore essential.

CO2 refrigeration applied to the cooling and heating of buildings shows a good deal of promise, both for retrofitting and in new buildings. In new buildings CO2 may also be used for zonal firefighting, avoiding the need to turn off the power supply to a building in case of fire for firefighters' safety. Lifts would remain operational and water damage to the building, frequently much greater than the fire damage, would be reduced.

CO2 cooling and heating systems are particularly suitable for installation into hospitals and hotels, both of which use large quantities of hot water.

In summary, CO2 has the potential to become the most ubiquitous refrigerant for all manner of applications from domestic heating and cooling, to refrigeration and freezers, to mobile air conditioning and all food processing and cold storage, to the largest district heating and cooling systems.

However, much larger compressors are required. Atlas Copco, General Electric, and some others have multistage compressors for natural gas compression up to 11,000 psi and pressurized crank cases up to 900 psi. Reconfiguring the piston and cylinders for CO2 is not a difficult job. Indeed, having different cylinder and piston configurations for different gases and stages is quite common. As an industry,

approaching these large companies may be desirable, although the author's efforts to date have failed.

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REFERENCES

Ball, J. and Visser, K. (2015). "The global application of efficient CO2 refrigeration enabled by evaporative condensers and gas coolers." IIAR Industrial Refrigeration Conference and Exhibition, San Diego, CA, 22–25 March 2015.

GEA Grasso. (2001). PowerPoint presentation at C-Dig meeting, Berlin, March 2.

Kriezi, E. et al. (2015). "Multi ejector and impact of ejector design on the operation of a CO2 refrigeration system". 6th IIR International Conference: Ammonia and CO2 refrigeration technologies. Ohrid, Macedonia, 16-18 April 2015.

Lorentzen, G. (1993.) "Revival of carbon dioxide as a refrigerant—Refrigeration beyond the crisis." Inst. of Refrigeration, London.

Minetto, S. et al. (2015). "Air conditioning and space heating with CO2: efficiency and improvement with ejector". 6th IIR International Conference: Ammonia and CO2 refrigeration technologies. Ohrid, Macedonia, 16-18 April 2015.

Pachai, A.C. et al. (2001) "CO2—Yesterday's buzzword—Today's real refrigerant."

Pearson, A.B. (2005). "Evaporator performance in carbon dioxide systems." Technical Paper #10, IIAR Ammonia Refrigeration Conference and Exhibition, Acapulco, Mexico.

Pearson, S.F. (1992). "Development of improved secondary refrigerants." Proc.Inst.R, 93,7–11.

Pearson, S.F. (1996). "Applications of carbon dioxide in industrial refrigeration." Nestle Refrigeration Workshop, Bjuv, Sweden.

Pearson, S.F. (2010). "Use of carbon dioxide for air conditioning and general refrigeration." 1st IIR Conference on Sustainability and the Cold Chain, Cambridge, UK, 29–31 March 2010.

Petterson, J. et al. (1995). "Recent advances in CO2 refrigeration." IIR B2, Theme 4, 19th International Congress of Refrigeration at The Hague, August 20–25, pp. 961– 968.

Stoecker, W.F. (1960.) "How to design and operate flooded evaporators for cooling air and liquids." Heating, Piping & Air Conditioning, December 1960.

Stoecker, W. (2000.) "Ammonia/carbon dioxide hybrid systems: Advantages and disadvantages." IIAR 22nd Annual Meeting, Nashville, TN, USA, March 19–22, 2000.

Svariegaard, C. (1996.) "CO2 as a refrigerant." Nestle Refrigeration Workshop, Bjuv, Sweden, September.

Visser, K. (2012). "A progress report on the world's first multi-function two stage transcritical CO2 refrigeration system." 10th IIR Gustav Lorentzen Natural Refrigerants Conference, Delft, the Netherlands, 25–27 June 2012.

Visser, K. (2014a). "A desk top study on the application of evaporative condensers for subcritical CO2 condensing." 3rd IIR International Conference on Sustainability and the Cold Chain, London, 23–25 June 2014.

Visser, K. (2014b). "The application of evaporative condensers for subcritical CO2 condensing and transcritical CO2 gas cooling." ATMOsphere America, Business Case: Natural Refrigerants, San Francisco, 18–19 June 2014.

Visser, K. (2014c). "The case for natural refrigerant CO2 in commercial buildings, hospitals and supermarkets in Melbourne to drive significant reductions in energy and cooling water consumption and both indirect and direct emissions." Presentation to 2nd Chinese Government Delegation, RMIT University, Melbourne, 25 September 2014.

Visser, K. (2014d). "The case for natural refrigerants including some examples for CO2 in commercial buildings, hospitals and supermarkets in Melbourne." CCN Live: Profiting in the Green Age, Sydney, 13 August 2014.

Visser, K. (2015a.) "CO2 evaporative condensers and gas coolers enable efficient CO2 refrigeration application worldwide irrespective of climate." 6th IIR International Conference: Ammonia and CO2 Refrigeration Technologies, Ohrid, Macedonia, 16–18 April 2015.

Visser, K. (2015b.) "The efficient use of subcritical CO2 refrigerating systems for cooling with on demand heating in transcritical mode." 3rd International Symposium on Energy Challenges & Mechanics, Aberdeen, Scotland, 7–9 July 2015.

Visser, K. (2016). "Building cooling and heating with transcritical CO2 system reduces energy and cooling water consumption and CO2e emissions." 4th IIR International Conference on Sustainability and the Cold Chain, Auckland, New Zealand, 7–9 April 2016.

Wiencke, B. (2010). "Computing the partial volume of pressure vessels." Int. Journal of Refrigeration, 33(2010), 868–876. Doi:10.1016/ijrefrig.2009.11.009.

Wiencke, B. (2011). "Fundamental principles for sizing and design of gravity separators for industrial refrigeration." Int. Journal of Refrigeration, 34(2011), 2092– 2108. Doi:10.1016/j.ijrefrig.2011.06.011.

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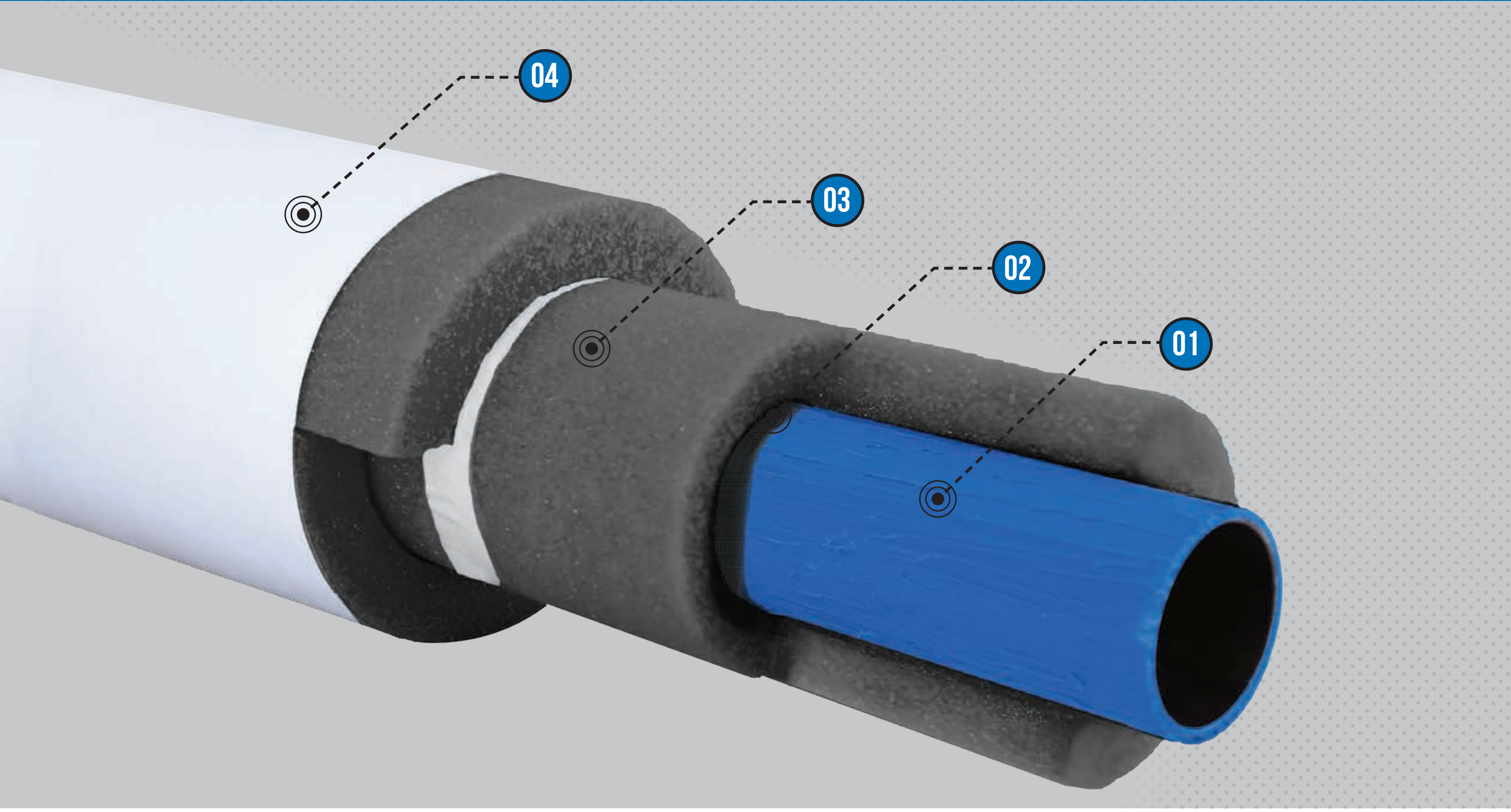

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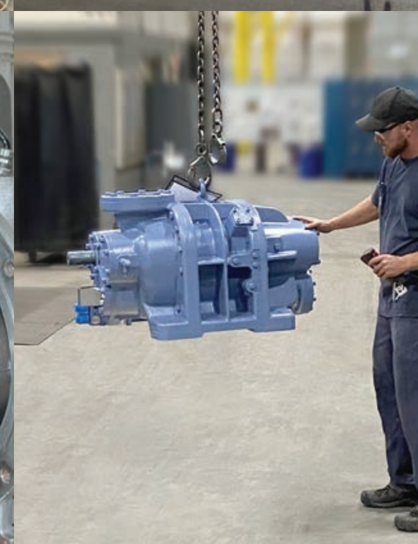

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