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CONDENSER

Are Natural Refrigerants the Only SURE BET?

AIM Act Advances as Industry Prepares for HFC Phasedown

CONDENSER STAFF

Publisher
Gary Schrift

Editor-In-Chief
Andrea Fischer

Staff Writer
Mindy Long

Creative Director
Bill Ellis

V.P. and Technical Director
Eric Smith

International Institute of Ammonia Refrigeration

1001 North Fairfax Street, Suite 503
Alexandria, VA 22314
www.iiar.org

Phone: 703-312-4200
Fax: 703-312-0065

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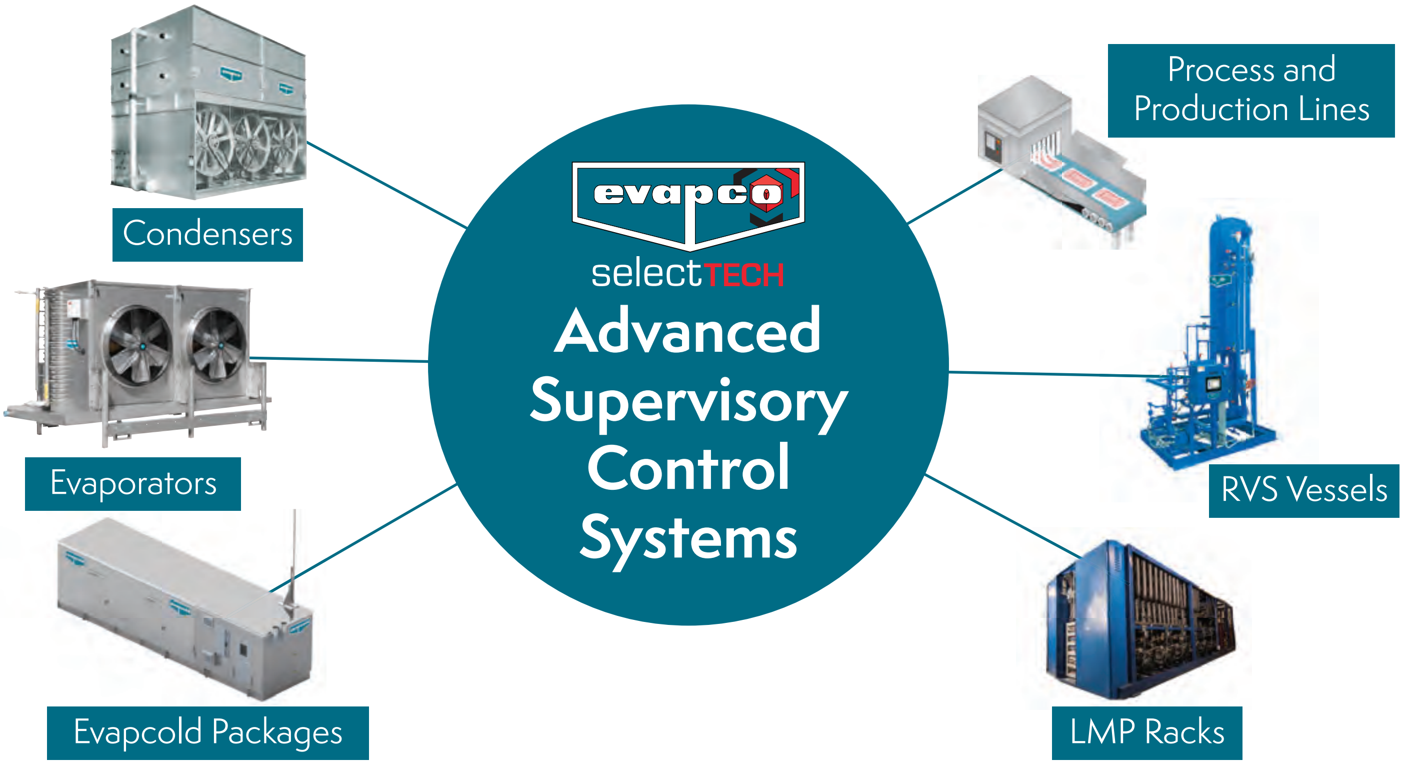

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The Natural Leader

IIAR Remembers

Chuck Hansen

Chuck Hansen, a serial entrepreneur who was always at the center of things, passionately expanding connections and networks to advance the natural refrigeration industry, build his visionary products, and mentor the next generation of engineers, has passed away at the age of 100.

Hansen was the founder of Hansen Technologies and Hantemp Controls, two of six companies he built and sold, and one of the founders of the International Institute of Ammonia Refrigeration.

"When you think about the valve technology footprint in this country, you can trace it all back to Chuck Hansen," said Santhosh Kumar, president of Hansen Technologies. "And what he contributed even more than the products was the mentoring of people who continue to serve the industry. He inspired so many people to come work in this industry, that is his legacy. For me, it all started with Chuck. He took a chance on me and lived his passion for innovation."

Santhosh, who came to industrial refrigeration right out of college, and immediately began working at Hansen Technologies was one of many people Chuck personally mentored. Friends and colleagues remembered Chuck as someone who genuinely cared about their future and the future of ammonia refrigeration.

"He was a very good leader and coach," said Mike Effrein, General Manager of Hantemp Controls, another early convert to ammonia refrigeration who recounted that he had no experience in industrial refrigeration when Chuck "encouraged me to jump in and give it a shot."

"That's how he was. Nobody got left behind on his team, nobody sat on the bench. He brought everyone up with him."

Chuck was interested in building a legacy through people beyond just his life, said Harold Streicher, IIAR member, past IIAR board member, and principal innovation officer for Hansen Technologies. "He was a mentor for me and someone who allowed me to grow in our industry. Chuck put the time effort and resources towards people. He was very good at identifying talent, but more importantly, developing and investing in talent."

Each of Chuck's companies offered generous tuition incentives to employees and an eventual endowment to MIT fully funded a perpetual fellowship in thermodynamics, but perhaps one of Chuck's most well-remembered contributions to industrial refrigeration was the formation of IIAR.

Chuck, with several other colleagues, founded the International Institute of Ammonia Refrigeration in response to pending government regulations that threatened the industry's use of ammonia in industrial refrig-

eration. IIAR's purpose, as envisioned by Chuck and several other founders, was to create an organization to educate and reassure regulators that ammonia could be safe and controlled using appropriate methods.

John Yencho, former VP of engineering for Hansen Technologies and employee of 35 years remembers Chuck's involvement in IIAR's formation as another example of his foresight and lifelong focus on innovation.

"Chuck knew that for ammonia refrigeration to see wider adoption, we needed to show that it was safer to use. His real love was creating new products. Looking at the industry and making sure it stayed healthy and was growing as far as valves and controls were concerned," and beyond that, making sure everyone stayed connected and invested in each other's work through industry organizations like IIAR.

"He was just one step ahead of everybody when it came to where the market was going and the future of where industrial refrigeration was going," said Yencho. "His main contribution was to help advance [valve] technology to where we are today."

Chuck realized that valves and control technology was at the epicenter of safety, Yencho said. "He started converting older-style flange valves that had been in use for ages to weld-in-line valve construction. And he switched from cast iron to all steel valves so they could be welded directly to the pipe, significantly reducing leakage."

"His innovations helped in all valve designs."

Kumar emphasized that Chuck was focused on innovation, a value that got baked into Hansen's identity as a company. "He always said to me, solve the industry's most difficult problems, and do it most uniquely."

Before founding Hansen Technologies, Chuck started his industrial refrigeration career at Refrigerating Specialties, the family business founded by his grandfather.

Under Chuck's leadership, RS grew significantly and introduced a wave of new products which allowed it to expand into international markets. He eventually sold the company to Parker Hannifin where he became a group vice-president.

Chuck then left Parker Hannifin after several years to start Hansen Technologies, which was eventually sold to Roper Industries. After Hansen Technologies, Chuck founded Hantemp Controls, at the age of 90.

Even in the last decade of his life, Chuck was spotting technology opportunities, said Hantemp's Effrein.

At Hantemp, Chuck and his team introduced high-capacity stainless steel ball valves rated at a higher pressure than traditional valves, offering higher flow capacity.

"Especially for full port ball valves, they significantly reduce the pressure drop in suction lines which reduces energy consumption," said Effrein. "He saw the potential for that, and we've come full circle because one of our biggest concerns now as an industry is energy consumption."

"Chuck was a force of nature unto itself," said Effrein. "We need people like that in our industry. He was 100 percent committed to a cause and even more importantly - to everyone around him. He will be missed."

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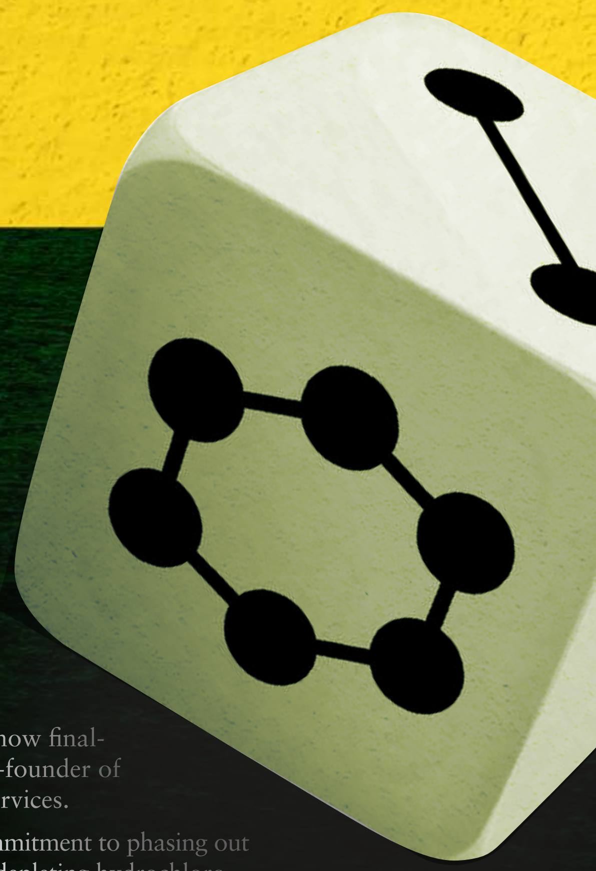
ARE NATURAL REFRIGERANTS THE ONLY SURE BET?

AIM ACT ADVANCES AS INDUSTRY PREPARES FOR HFC PHASEDOWN



THE AIM ACT ADVANCES

THE U.S. ENVIRONMENTAL PROTECTION AGENCY HAS FINALIZED THE SECOND REGULATION UNDER THE AMERICAN INNOVATION AND MANUFACTURING ACT, ADVANCING RULES THAT WILL RESTRICT THE USE OF HYDROFLUOROCARBONS.

"With the second regulation finalized, the EPA is addressing technology transition. It previously focused on production and consumption and will next consider and rule on refrigerant management.

"We have two legs of the three-legged stool of the AIM Act now finalized, and the third leg now proposed" said Tristam Coffin, co-founder of Effecterra and president of sustainability, policy and technical services.

Gary Schrift, president of IIAR, said AIM solidifies the nation's commitment to phasing out hydrofluorocarbon refrigerants in the same manner that ozone-depleting hydrochlorofluorocarbon refrigerants were phased out.

"Natural refrigerants have a big opportunity to be the hero of the AIM Act," said Danielle Wright, executive director of the North American Sustainable Refrigeration Council.

Those within the natural refrigerant space said the phasedown will create potential for growth. "People in our industry that support

and understand natural refrigerants should be optimistic about the newer markets that become available," said David Fauser, director of sales at Cimco Refrigeration. "As the economy slows in certain areas, such as food and beverage, now there is a whole new world of opportunities."

The AIM Act has focused on three areas: production and consumption, technology and transitions, and, most recently, refrigerant management. "Each use sector has different timelines and refrigerant global-warming potential levels for reduction and phaseout," Schrift said.

The EPA has taken lessons from the European Union, which experienced price spikes and limited availability of refrigerants. EPA is "putting actions in place to help manage demand and hopefully not see the same volatility the EU saw," Coffin said.

The first of the final rules, which focuses on the phasedown of production and consumption, was published July 20, and the first major phase down under the rule is coming on Jan. 1. "It is a 40 percent reduction in supply. The refrigerants with the highest GWP [global-warming potential] will be targeted first," Coffin said.

The rule authorizes EPA to slash U.S. production and consumption of HFCs by 85 percent by 2036. The phasedown is consistent with the Kigali Amendment to the Montreal Protocol, and establishes a baseline and methodology for allocating and trading HFC allowances and creates compliance and enforcement systems.

EPA finalized the second rule, which focuses on technology transitions, on Oct. 6. The technology transitions rule puts GWP limits on specific refrigerant applications, Coffin said. "We're looking at 150 GWP for commercial refrigeration systems with greater than 200 lbs. of refrigerant, for example, by Jan. 1, 2027, and then there is a whole list of applications in terms of their dates and when they will transition to the GWP thresholds that are going into place."

GWP scores are ratios that compare the global-warming potential of a given compound with carbon dioxide, which has a score of 1.0. Between 2025 and 2028, there will be restrictions on the sale of high GWP applications for air conditioning ranging from commercial and industrial.

"As the phasedown continues, it will become more and more difficult to access HFCs to service existing equipment, which is why we are seeing a growing number of end users developing roadmaps to transition their existing facilities to ultra-low global warming potential equipment," Wright said.

The last rule to be finalized under AIM will focus on refrigerant management. It will establish an emissions and reclamation program for the management of certain HFCs and their substitutes that apply to both new and existing equipment in certain sectors and subsectors. "We have about a year until we see this rule finalized," Coffin said.

"A year after it is finalized, and if this sticks, they're going to drop the charge threshold from 50 to 15 pounds for refrigerants with a GWP equal to or greater than 53," Coffin said. "It is a significant jump in terms of managing these emissions."

Fauser said the AIM Act is complicated. He recommends that IIAR members take advantage of the AIM resources available on IIAR's website (www.iiar.org/AimAct).

Many organizations, including IIAR, are working on simple ways to convey information about the act, according to Schrift. "IIAR/NRF's Education Committee is working on a Refrigerant Evaluator tool," he said, adding that once end users fully understand the impact of the HFC phasedown, IIAR members will see significant growth in inquiries for natural refrigerant systems in the United States.

Those in the industry need to know why HFC refrigerants are phasing down or prohibited and when this will occur so they can alert their end users. Schrift recommended they share insights with customers on when to change their refrigeration systems and warn them if their existing refrigerants may become difficult and expensive to purchase. End users also need to know how new regulations will affect the inventory of their current hydrofluorocarbon refrigerants.

HFC price spikes could come as early as next year, but Wright said the real pinch will come in 2029 when the allocation allowance cap drops to just 30 percent. "At that point, we expect to see impacts to the supply and price of HFC-blends and other 'medium-GWP' refrigerants," she said, adding that if EPA's proposed HFC refrigerant management rule is adopted, only reclaimed HFC refrigerants will be allowed starting in January 2028.

Fauser said companies should start thinking outside the box and consider new ways to apply natural refrigerant technology. "We should think about how we can help other industries," Fauser said.

IIAR MEMBERS:
Take advantage of the AIM resources available on IIAR's website (www.iiar.org/AimAct).

For example, Cimco Refrigeration is now completing residential projects on a large-scale basis and is making package systems for non-traditional markets.

Wright said the refrigeration sector is poised to enter a rapid acceleration in the adoption of natural refrigerants. "This isn't our first rodeo. We've gone through a major refrigerant transition before. We know that these transitions are costly, logistically challenging, and have a disproportionate impact on small businesses," she said.

However, natural refrigerants offer a future-proof, climate-friendly, and technically viable alternative to HFCs. "We can have a successful transition to natural refrigerants if we build and train our technician workforce, maximize incentive programs and other funding mechanisms, especially for small businesses, and optimize technologies to provide end users with a variety of options," Wright said.

Even with the final rule coming next year, Fauser said, the AIM Act is, in a sense, never going to be finished until we have zero GWP across the board. "There is enough evidence of natural refrigerants working in certain areas that it could go to a lower global warming potential than what is stated," he explained, adding that end-users should also look beyond AIM. "Requirements aren't going to go back up again. They're only going to get lower."

Businesses that rely on HFCs should have a plan to transition away now. "The biggest bottleneck is the critical shortage of refrigeration technicians. The sooner the transition begins, the better off we will all be," Wright explained. "Everyone needs to do their part to increase technician access to training on the latest natural refrigerant technologies and prepare the workforce for this shift."

Tony Lundell, senior director of standards and safety for IIAR, said he recommends companies turn to natural refrigerants any chance they get to avoid having to make changes later. "There are companies out there that have switched to another high GWP refrigerant, then just a few years later will now have to make a change," he said. "Go for the naturals now rather than taking a step that will just have to be replaced again."

According to Wright, natural refrigerants are currently the only future-proof option that are not at risk of facing additional regulatory restrictions. "Right now, Europe's phasedown is at a 45 percent allowance cap, and we are seeing natural refrigerants as a leading choice for food retailers in Europe. We can expect to see a similar trend here as the regulations progress," she said.

Coffin agreed that there is "underlying writing on the wall to just go to naturals. Otherwise, you're just kind of putting yourself in a position where it is going to be extremely hard to get access to synthetic refrigerants," he said, adding that he recommends end-users establish a refrigerant roadmap that creates a path to transition to natural refrigerants. "If you haven't already, you should start applying refrigerant management best practices."


Your Next Move Is
CO2

Private Equity Interest in Refrigeration Continues to Increase

Several industries are experiencing consolidation, including refrigeration, and Condenser sat down with **Harry Gray**, CEO of Kelvin Group, to learn more about changes that are taking place.

Q *Let's start by talking about Kelvin Group's acquisitions. How many companies have you acquired?*

A We've acquired nine so far. We've grown a lot in a short amount of time, and we're still very much in acquisition pursuit, maybe even more than ever.

Q *Is there anything specific you're looking for in new acquisitions?*

A We are well-known for industrial refrigeration, but we also have fast-growing industrial HVAC and commercial refrigeration. We can offer them resources they wouldn't have had otherwise from an innovation, recruiting, fleet management, global safety, and supply chain standpoint. We have a vision and a strategy and companies are going to get more customers just by sharing the Kelvin Group wallet.

Q *Why are we seeing private equity interest in refrigeration increase?*

A The private equity industry has an abundance of dry powder. Funds are bigger than ever, and they need to find a way to deploy it. If you were to describe the attributes of a PE play, they often like things that won't be offshored. They want an industry that will always be here, and they like fragmentation.

There is a lot of attractiveness in the refrigeration space. For us, in industrial refrigeration, it is the beginning of the cold chain. Without the customers we have, you don't have food or drugs. The more steady service mix a company in our space has, the more recession-resilient you are. Assets have to be maintained. In our experience, recessionary times can be a boom for service even if companies are deferring projects. We work very hard on our mix.

I would imagine most industrial refrigeration businesses are still founder-owned, and these companies eventually need a generational transfer.

Q *Is labor availability, such as technicians, driving any consolidation?*

A There is a nationwide macroeconomic issue, which is that we've persuaded America's youth to pursue paths outside of the trades. We should be advocating for the trades. Some trades pay very well, and you're always going to be in demand. The labor statistics point out that there aren't enough Americans in the trades.

For us, we work very feverishly to focus on the field, the engagement, the safety, the training, and the morale. At Kelvin Group, the technician who is working, in some instances seven days a week, is the lifeblood of our company. You need to pay fairly, treat them fairly, offer good benefits, and grow their careers. The next challenge is bringing in the younger people, so you don't have a generational gap. We have Kelvin University, so we can put them through our curriculum, and we can help them grow with us.

Q *What are the challenges with consolidation?*

A The hardest thing about consolidation or integration is the cultural piece. Systems integration and process implementation are easily the hardest parts of cultural integration.

Kelvin Group at a Glance

- Field Technicians
- 300+ Employees
- Offices in New England, Mid-Atlantic & Southeast U.S.
- Nine (9) acquisitions since 2018

Q *How do you build the culture?*

A In my role, I try to be very closely connected with the field. I pick up the phone and try my best to call technicians all of the time. I conduct a number of communications across our company featuring employees. We try to build a culture where the business unit presidents and executives are also in the field. If you are engaged with your field, you're engaged with your customer.

The hardest thing about consolidation or integration is the cultural piece. Systems integration and process implementation are easily the hardest parts of cultural integration.

In most businesses, the founder is still around in some way. During the transition period, we're always better off when we explain and walk them through what the entire experience is going to be early on and help them ease into it. We discuss the new cadence, new types of reporting, and different controls. The main thing is to not let that deviation from what they're accustomed to create anxiety.

We try to make the business fun again for the new teammates. We work very hard at making them feel like a part of the family. In many cases, they're selling the family business to become part of a bigger family. If we're interested in their business, it is because they've proven a dedication to the field and customers. If we can get them back in the fun part and demonstrate we can take care of their employees, that is valuable.

Training Provides Guidance and Insights for OSHA Field Personnel

IIAR, the Industrial Refrigeration Consortium (IRC), and the Global Cold Chain Alliance are continuing their work to provide information on ammonia systems, including their principles of operation, major subsystem components, and materials of construction, to the Occupational Safety and Health Administration's compliance safety and health officers. Two trainings took place in 2023 and the groups plan to offer it again in 2024.

Mike Chapman, director of business operations for IIAR, said the training is invaluable to any inspector ith inspection responsibilities for Risk Management Programs and Process Safety Management Programs. "An educated inspector is much more valuable to our industry than an uneducated one," he said. "Educated inspectors know what they're looking, look for the stuff that needs to be found, and, if they find it, the facility can address it for the minimization of risks."

The course provides in-depth coverage of IIAR's standards, identifies IIAR guideline documents, and gives participants access to the IIAR Government Portal. "The course also covers some basics of mechanical integrity as it applies to ammonia refrigeration systems since this has been a significant point of confusion with compliance safety and health officers (CSHOs) in the past," said Doug Reindl, professor of mechanical engineering and director of the IRC at the University of Wisconsin-Madison, and the course instructor.

OSHA's National Emphasis Program includes provisions that require OSHA to conduct PSM inspections of ammonia-refrigerated facilities. "In the somewhat distant past, CSHOs did not have a foundational grounding in ammonia refrigeration systems and technologies and issues arose when they attempted to apply other kindred industry standards as RAGAGEP to these facilities," Reindl said. "Part of the role of this training is to connect CSHOs with the RAGAGEP that applies to the ammonia refrigeration industry.

The target audience for the training is field personnel who will be conducting inspections of ammonia-refrigerated facilities.

The course's learning objectives give CSHOs an understanding of: industrial ammonia refrigeration systems and their principles of operation; the types of engineered safety systems applied to ammonia refrigeration technology; the RAGAGEP that applies to industrial ammonia refrigeration systems; and the common failure mechanics that can compromise the mechanical integrity of industrial ammonia refrigeration systems.

Reindl said the feedback from the attendees has been positive. "End-users that have longitudinal experience in interacting with OSHA personnel before the training was available and OSHA personnel that have taken training note that their inspections/interactions with CSHOs are much more productive," he said. "They can more clearly communicate with the CSHOs in a language both understand."

This online CSHO training was an outgrowth of an F2F course the IRC has been delivering to EPA inspectors for more than a decade. "Some OSHA personnel were able to participate in the F2F class and found it very beneficial," Reindl said. "That led to OSHA seeking an opportunity to receive a trimmed-down version of the EPA course but in an online synchronous format since they are much more travel-restricted.

Chapman said that, overall, inspectors are trying to make sure facilities are doing what they are supposed to do. "Facility operators want to do the right thing. With the right training, they can interface with inspectors better," he said. "When the inspectors arrive and have a seamless interaction with facility operations personnel and each are using understandable jargon, it's a win-win."

EPA Publishes Final Technology Transitions Rule to Phase Down HFCs

iiar government RELATIONS

BY LOWELL RANDEL, IIAR GOVERNMENT RELATIONS DIRECTOR

On October 5th, Environmental Protection Agency (EPA) Administrator Michael Regan signed the Final Rule Technology Transitions authorized under the American Innovation and Manufacturing Act designed to phase down hydrofluorocarbon (HFC) use. The AIM Act authorizes EPA to address HFCs in three main ways: (1) phasing down their production and consumption, (2) promulgating certain regulations for purposes of maximizing reclamation and minimizing releases of HFCs from equipment and ensuring the safety of technicians and consumers, and (3) facilitating the transition to next-generation technologies through sector-based restrictions.

The AIM Act included a process by which interested stakeholders could petition EPA to establish sector specific policies regarding the phase down of HFCs. IIAR submitted a petition to EPA recommending phase down policies related to the refrigeration sector. IIAR's petition, along with petitions from several other groups, was granted by EPA in October 2021, triggering EPA to initiate a rulemaking process. The Final Technology Transitions Rule addresses IIAR's petition and is largely consistent with the policies recommended by IIAR. The Final Technology Transitions Rule restricts the use of higher-GWP HFCs in new aerosol, foam, and refrigeration, air conditioning, and heat pump (RACHP) products and equipment. EPA has listed entities potentially impacted by the rule to include companies that manufacture, import, export, package, sell or otherwise distribute products that use or are intended to use HFCs, such as refrigeration and air-conditioning systems, heat pumps, foams, and aerosols.

The rule provides three mechanisms to restrict HFC use:

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

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

The chart below displays provisions for selected subsectors covered by the rule.

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

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

Assembling a system for the first time from used or new components

Increasing the cooling capacity, in BTU per hour, of an existing system

Replacing 75 percent or more of evaporators (by number) and 100 percent of the compressor racks, condensers, and connected evaporator loads of an existing system.

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

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

Filling Levels of Pressure Vessels by Volume for Refrigerants

In the ammonia refrigeration industry, maintaining the proper filling levels of pressure vessels is essential for safety, efficiency, and regulatory compliance. Appropriately filled vessel ensures that ammonia refrigeration systems operate optimally, reducing energy consumption and preventing safety hazards.

"Geographical locations and weather conditions can cause thermostatic or hydrostatic expansion depending on temperatures in the area, which is why we require over-pressure protection," said Tony Lundell, senior director of standards and safety for IIAR.

Lundell explained that in the refrigeration industry, it is common practice to limit the filling of receiver vessels of any refrigerant to 90% by volume, with a refrigerant temperature of 90°F (32°C). "This has been included in codes and standards for many decades," he said.

ANSI/IIAR 2-2021 takes a somewhat different approach, recognizing that conditions may vary, and requires that fill volumes be limited to eliminate the risk of hydrostatic overpressure, or otherwise be protected by ASME liquid service relief valves. The traditional value of 90% at 90°F is also provided as guidance.

ANSI/IIAR 2-2021 has the following normative and informative sections:

5.16.2 *Vessel Pumpdown Capacity. Liquid ammonia shall not occupy a vessel at a volume large enough to create a risk of hydrostatic overpressure unless the vessel is protected by a liquid pressure relief device.

(Informative) Appendix A:

A.5.16.2

The maximum volume of liquid in vessels has traditionally been considered 90% at a temperature of 90°F. Calculations can be done to determine other levels and worst-case temperatures. If liquid pressure relief is used to protect against overpressure due to hydraulic expansion, the requirement for atmospheric relief is not eliminated if it is required elsewhere in this standard.

6.6.3 *Connection of Ammonia Cylinders. Ammonia cylinders shall not be connected to a refrigeration system unless ammonia is in the process of being transferred by authorized personnel.

(Informative) Appendix A:

A.6.6.3

Ammonia charging cylinders are not considered part of the closed-circuit refrigeration system. Facility designers are nonetheless urged to consider where and how charging cylinders might be stored. The Compressed Gas Association document CGA-G-2.1 Requirements for the Storage and Handling of Anhydrous Ammonia provides guidance on the topic of storage. The International Fire Code, Section 5003, addresses building requirements for the storage of hazardous materials. Closed-circuit refrigeration systems are not subject to the IFC, Section 5003 requirements.

Lundell added that if a high side pressure receiver vessel is located outdoors and exposed to an extreme seasonal hot climate, operating the pressure vessel at a maximum of 80% would help protect against the lifting of an overpressure protection device due to a thermostatic or hydrostatic increase or fluctuation in pressure.

Guess Who's Coming to Visit?

In the industrial ammonia refrigeration industry, we make a considerable effort to stay informed and up to date on programs that should be followed. The effort put into these programs varies depending on factors such as the specific system design and operation; the resources (people) available; the effort that can be done on programs due to other commitments; or if no one has a really good understanding of requirements. Whatever the situation, there likely will come a time of reckoning when some outside agency wants to review what is in place.

Recently I received a call from a company I was helping to develop and maintain their OSHA Process Safety Management (PSM) and EPA Risk Management Plan (RMP).

The conversation went something like this:

"I just got a letter that EPA is coming to visit in 10 days!"

"What's the date they are coming," I asked.

"August 15th, and I'm out of town on vacation that whole week," he replied.

Couple of learning points here:

1) EPA typically gives a two-week notice, but it sometimes may seem shorter as it did in this case. Part of the challenge is who does the notice go to? I have seen some notices ending up taking several days before they actually got to a person who understood what it meant.

2) It doesn't matter if you are on vacation or attending an important event somewhere. Someone must be on site to properly represent your program to the EPA. It is important that more than just person at your business has a good grasp of the entire program.

Our conversation continued with my reply, "When can we get together?"

I know several companies that have people dedicated specifically to oversee programs such as the PSM and RMP. These people and companies put in the continuing effort needed to keep all sections of these programs in "current" condition so they can be seen as "living," not dust-collecting stacks of papers and books.

After I hung up, I wondered who else might be getting a visit? The answer came quickly when another customer called. Their inspection would be three days later. The gentleman calling felt very unprepared and wanted to meet ASAP.

EPA inspections for a Risk Management Program typically have three parts.

1) After an introductory discussion on the inspection agenda, they ask to be taken on a tour of the refrigeration system of your facility, including the machine room(s) and several of the cold rooms or refrigeration processing areas. One of the people in the EPA group will likely be taking photos to document what was actually seen as they tour.

2) They divide all of the sections of your program among however many inspectors there are. From my experience, there have always been three inspectors. First impressions of your program do make a difference. A lesson to learn is that your program presentation should be well organized, with each section easily identified, and that all the appropriate information can easily be found. It has worked best when most of the sections (or elements) are in their own binder, although some of the smaller sections might be combined into a single binder with easy-to-understand separation between the sections. I have seen facilities that have placed everything into a couple of large binders. These were very thick and hard to handle, and made it challenging to find information quickly.

3) They hold a wrap-up meeting with the company. Depending on the inspectors and how and what they found, they may spend some time in a private conversation before informing you of their preliminary findings. In other cases, where the inspection has found relatively little, a private meeting might not be held and the wrap-up is fairly quick.

It is important to understand that what the EPA inspectors note when going through their checklists are preliminary findings, and their inspection reports are turned over to another EPA person or group to analyze and eventually make recommendations and/or issue a fine notice that will be sent to you at a later date —maybe in several weeks or much longer.

With the notice of an upcoming inspection, EPA typically sends along their "RMP Program Level 3 Process Checklist." This document is presently 25 pages and covers 40 CFR Part 68 in good detail. This document can be helpful as companies compare the checklist to their current program, finding out where things seem to be in good shape or may be deficient.

Consider the following as you prepare for an EPA inspection:

- The refrigeration system and facility in general should be fairly clean so it can be seen it is being well maintained. Again, first impressions do help.

- The system and its components should be properly labeled (See ANSI/IIAR 2-2021, Appendix Q (Informative) Guidelines for the Identification of Ammonia Refrigeration Piping and System Components). Inspectors are typically familiar with industry standards and guidelines. How does your system compare to the standards and guidelines?

- Drawings, Piping and Instrumentation Diagrams (P&IDs) should be accurate. I have been on inspections where the EPA inspector got information from the P&IDs then went to the field to verify it was the same. Also, taking information from the field and verifying it was the same on the P&IDs. Drawings should be field verified for accuracy before any inspectors see them.

- How are all of the PSM/RMP sections presented? As mentioned above, the best documentation presentations seem to be when each section of your program is distinctly separated. Usually, this means that each section is in its own binder. This makes it much easier for the inspectors and also for you when you are asked where something is. I have seen several inspections where most of the sections were combined into one or two large notebooks. These inspections were much more stressful. You may know your program very well, but under the stress of having multiple inspectors looking at you for answers you may find you have momentarily lost several grades of intelligence. Be very organized beforehand so you have to put less thought into where materials are located, whether in binders or electronic files.

- Be truthful, helpful and forthcoming when asked questions. Answer questions without stating information beyond what is needed. Do not dig a hole you can fall into.

- Be pleasant. I can't think of an EPA inspector that hasn't been pleasant to work with as they do the job they came to do. Don't create the impression that you have more important things to do than sit here with the inspectors or spend time on the PSM/RMP programs.

Regarding the two inspections I mentioned, one did much better than the other. The first inspection did not have documentation as well organized as it could have. There were some duplicate sections, and sometimes in multiple places. The feeling was, "Don't throw anything away." That may work sometimes, but for these programs and inspections you want the current version of each section. Older information should be archived, possibly electronically, and retrieved if needed to show a history of compliance.

You should be familiar with the retention time for sections of the RMP. In 40 CFR Part 68.200 Recordkeeping it states, "The owner or operator shall maintain records supporting the implementation of this part at the stationary source for five years, unless otherwise provided in subpart D of this part."

There is information in some sections that should be kept for other periods of time. For example, you should retain the two most recent "Compliance Audits" along with documentation of tracking of resolutions to all recommendations; every "Process Hazard Analysis" (PHA) that has been done including documentation of tracking of resolutions to all recommendations for the life of the process. For other sections of the programs, when in doubt, keep the information for five years.

When someone of authority comes to inspect your PSM and RMP programs, the best way to be prepared is by constantly keeping these programs as current as possible. Keep relevant information as up to date as feasible. This will help you, your team and company have a much less stressful cortisol flowing experience when OSHA or EPA come to visit.

IIAR Takes its Training on the Road for Trident Seafoods

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

Sources: Esri, tridentseafoods.com MARK NOWLIN / THE SEATTLE TIMES

Training is essential for anyone working with refrigerants, and IIAR has a long history of serving as a valuable resource for education and training for its members. The association recently took that support to the next level for Trident Seafoods in Alaska.

"Being in Alaska, remote from the other USA states, it's hard for everyone to make it to the IIAR conference, so remote workshops like this give our team the proper exposure to new standards and in-person interaction with the requested experts," said Bill Jensen, division manager of refrigeration for Trident Seafoods.

To support its training efforts, Trident Seafoods asked Tony Lundell, senior director of standards and safety for IIAR, to attend its Process Safety Management (PSM) compliance training session and brought its employees together at its Anchorage office.

In addition to Tony providing instruction at this event, Jim Barron, executive director of the Refrigeration Engineers and Technicians Association, provided sessions that pertained to RETA Certifications and a RETA Chapter consideration.

Trident Seafoods had either a PSM coordinator, assistant chief engineer, or chief engineer from each Trident facility take part in the training. Also in attendance were the company's vice president of safety, Holly Armstrong, and director of environmental, Shawn Stokes.

Lundell said Trident Seafoods was passionate about meeting the IIAR Standard requirements, and he covered a range of topics, including what to do during seasonal shutdowns of facilities, General Duty Clause requirements, Mechanical Integrity – Inspection, Testing, and Maintenance Tasks, and Recognized and Generally Accepted Good Engineering Practices (RAGAGEP). He also covered the IIAR Suite of Standards for Ammonia Refrigeration Systems, especially IIAR 2, IIAR 6, and IIAR 9, and the latest adoptions of IIAR Standards by Model Codes.

"The training provided the latest for the standards and topics, as well as provided answers to any questions during the training as it progressed," Lundell said.

The training on IIAR 6 was especially helpful, Jensen said. "You have maintenance and inspection programs for when you're continuously in operation, but there wasn't a breakdown of what you do in the offseason when there is ammonia, but it is dormant," he explained.

Participants also took part in an interactive session to provide input and wordsmith a new section that will be included in the next revision of IIAR 6, which is targeted to be completed in 2024.

The new Section 5.6.11 Out-of-Service, which pertains to while equipment is locked/tagged out, tagged out-of-

service, or disabled from operating, coincides with the seasonal shutdown of facilities. "For Trident Seafoods, a vast majority of their 13 facilities in Alaska operate with four to eight months of idle periods," Lundell said.

Helping Trident Seafoods, and other similar industries with seasonal harvesting "idle" periods of operation, will help IIAR provide a clear directive on how to document inspection, testing, and maintenance tasks during that idle time. "It will also help to clarify how seasonal shutdown facilities can start back up for the new season that will bolster their Mechanical Integrity programs and RAGAGEP," Lundell said.

EDUCATIONAL OFFERINGS

IIAR members can take advantage of several useful resources from IIAR to aid in their education and training efforts.

"The refrigeration industry has different levels of operators, different levels of technicians, different levels of Process Safety Management (PSM) coordinators, different levels and types of engineers, and different levels of Environmental, Health and Safety (EHS) employees that benefit from the information and teachings provided in the different standards, certificate classes, and webinars," Lundell said.

IIAR has a wide range of self-taught and self-paced training programs available online. "Our main support is through our Online Academy of Natural Refrigerants classes, our online video series classes, our technical programs at conference, our online webinars, and answering emails from members," Schrift said. "But we also, at times provide in-person onsite training as done with Trident."

IIAR considers in-person training opportunities if members have a developed program and could use the support of IIAR as part of their program. Participation is dependent on staff members' expertise and availability and members cover the costs for IIAR staff travel and living expenses.

"A company can consider what training they want and work through a plan to have it arranged and provided, either through existing established materials, or an arrangement that can be presented," Lundell said.

New Report Offers Insights, Availability of and Use Cases for Natural Refrigerants

A new report prepared for the New York State Department of Conservation highlights opportunities for and barriers to the adoption of natural refrigerants, outlines the availability of natural refrigerants by end-use sector, provides recommendations and considerations for policymakers to address the obstacles to natural refrigerants adoption, and lists ideas for pilot projects.

"New York state laws require a very ambitious greenhouse gas reduction, and they realize they must move even faster than what laws such as the EPA AIM Act rules are requiring - to meet their reductions," said Gary Schrift, president of IIAR. "They are looking at ways to go further, and they know that refrigeration as an energy user and the release of synthetic refrigerants cause a great amount of GHG emissions."

Effecterra prepared the report, New York State Assessment of Natural Refrigerants. Tristam Coffin, co-founder of Effecterra and president of sustainability, policy and technical services, said the report adds another layer of information that otherwise wouldn't be available. "They tasked us to bring together a group of subject matter experts from a cross-sector who have gone through transitions and were familiar with the technologies available, deployed, and still needed" Coffin said. "There was an extensive group of people that participated."

Effecterra held eight working group meetings with stakeholders to discuss the challenges and opportunities for natural refrigerants/heat transfer fluids by end-use. The working groups consisted of climate science experts, state policymakers, state and city officials, non-profit advocacy organizations, equipment manufacturers, and engineering experts who either directly work with natural refrigerants or have highlighted the need for addressing the barriers.

> "The working group meetings were designed to bring sector-specific experts and stakeholders to the table to share the opportunities and barriers to transitioning to natural refrigerants."
>
> **Danielle Wright, executive director of the North American Sustainable Refrigeration Council and co-lead of the working group Stationary Refrigeration: Retail Food and Other Commercial Refrigeration.**

Different groups and experts co-hosted technical working groups. "The working group meetings were designed to bring sector-specific experts and stakeholders to the table to share the opportunities and barriers to transitioning to natural refrigerants," said Danielle Wright, executive director of the North American Sustainable Refrigeration Council and co-lead of the working group Stationary Refrigeration: Retail Food and Other Commercial Refrigeration.

Topics included retail food and commercial refrigeration, industrial process refrigeration and cold storage warehouses, chillers, safety standards, and commercial and residential air conditioners and heat pumps. "It wasn't just one single voice leading the conversation," Coffin said. "We played a prime coordinator role, but it was purposefully a cross-sector collaboration."

Dave Fauser, director of sales at Cimco Refrigeration and co-leader of the chiller working group, said the report shows that the world is changing and evolving, not just in the food and beverage space but also in data centers, electric vehicle manufacturing centers, and more. "All of these spaces are now looking to naturals. They are the solution if we want to fight climate change," he said.

The report identifies natural refrigerant applications currently available, what's coming to market, and possible projects identified by members of the technical working group. "This is the only report I'm aware of that provides a comprehensive assessment of the availability of natural refrigerants across all end-use sectors," Wright said.

For Fauser, the big thing that stands out from the report is that natural refrigerants are a great solution. "We can use them in many different applications," Fauser said. "When I started 20 years ago, if I'd brought these ideas up, I'd have been laughed out of the room. Now I'm reading these quite interesting ideas, and it is motivational to me. When we start to see them in other industries, it becomes exciting."

One of the pilot projects addresses heating, cooling, and refrigeration for ice rinks. "We talked about our concept of Thermal Force One—a single unit that does heating and air conditioning using ammonia as a refrigerant," Fauser said.

Cimco is working with a town in New York to build a multipurpose venue comprising an ice rink, gymnasium, indoor turf, daycare, and play structure. "What makes this technology interesting and why this would be a good study is the ice rink now becomes the byproduct," Fauser said. "We can use that thermal energy, and we could heat or cool a neighborhood of homes. This is a case study we put forward to say natural refrigerants could replace furnaces."

Other pilot projects address ammonia absorption heat pump systems for space-conditioning and water heating and combination heat pumps for space

heating and domestic water heating using CO_2.

Fauser said he encourages everyone in the industry to push the boundaries and share the success stories of moving into new markets. “That is what we need more than anything to fight climate change,” Fauser said.

There are various challenges preventing the greater adoption of natural refrigerants in the U.S., such as delays in adopting updated safety standards into state and local building codes and misinformation about the safety and energy efficiency of natural refrigerants. “We all know that natural refrigerants have risks, but so do all refrigerant options. Because natural refrigerants have been used for over 150 years, the risks are known, understood and mitigated by the use of modern technologies,” Coffin said.

The report found that standards need to be updated to allow greater use of natural refrigerants. “These changes don’t happen overnight, and it has slowed down the wider adoption of these types of refrigerants, mostly hydrocarbons,” he explained, adding that bringing industry participants together can help break down barriers. “It takes decades of work and international collaboration. We need to continue acting on that and pressing forward.”

Wright said greater coordination on building codes is needed. “Section 606.1.1 of the NYC Fire Code is a great example of a ridiculously outdated code that is obsolete but politically motivated,” she said. “Getting local codes updated to reflect the latest safety standards and model codes will take longer than it should unless there is active coordination at every level.”

Additionally, more clarity on per- and polyfluoroalkyl substances – known as PFAS – is needed. “Providing clarity on PFAS will give retailers and other end-users the certainty they need to weigh the costs and benefits of naturals against various alternatives,” Wright said. “Natural refrigerant solutions may have higher first costs compared to interim solutions but will prove to be more cost-effective if those solutions are eventually phased out as well.”

Some end-uses, such as commercial, industrial refrigeration, cold storage, and ice rinks, are well on their way to switching to naturals. However, they need greater incentive funding to help achieve economies of scale, retrofit existing buildings, and address workforce readiness challenges.

“End users are switching to naturals or have already, but there is a greater need for incentive funding. There are opportunities under the Inflation Reduction Act to support or help achieve the economies of scale necessary to continue to allow the market barriers to fall off and these solutions come to market,” Coffin said.

Coffin said one of the biggest challenges and opportunities is deploying natural refrigerants in AC and heat pumps, especially in the residential sector. “We need incentive funding and a paradigm shift in system design,” Coffin said, explaining that the U.S. has been addicted to low-cost high-efficiency rooftop units. “The combination of natural refrigerant heat pump solutions aren’t just possible. They’re here, and notably becoming commonplace in Europe.”

While the report was done in collaboration with New York State, it applies to anyone involved with refrigerants. “Other states can certainly use it, and companies interested in transitioning to natural refrigerants have been interested in looking at the report,” Coffin said. “In my mind, it is elevating the conversation. Everyone who is considering meeting their climate objectives needs to be thinking about these opportunities. They will be the clearest path to zero emissions going forward.”

Wright suggests anyone working in the refrigeration, air conditioning, and heat pump sector read the report. “I’ve referenced it in many conversations with national chain retailers, manufacturers, contractors, and government officials from other states working on refrigerant regulations,” she said.

Fauser said states that are moving forward on refrigerants can serve as an inspiration to others. “You have certain states like New York and California that are leaders. The innovators, early adopters, and trailblazers make it safe for the other states to follow behind,” he said. “People can say, ‘They did it, and now we’re going to go do it.’”

The report is available free online. Download the report at https://drive.google.com/file/d/14udH0WJhMqdeez6sj_PeTkClOR-GLdHXS/view or https://www.linkedin.com/posts/effecterra_new-york-state-assessment-of-natural-refrigerants-activity-7112918498481225728-1IqD.

> “What makes this technology interesting and why this would be a good study is the ice rink now becomes the byproduct. We can use that thermal energy, and we could heat or cool a neighborhood of homes. This is a case study we put forward to say natural refrigerants could replace furnaces.”
>
> **Dave Fauser, director of sales at Cimco Refrigeration and co-leader of the chiller working group**

IIAR Committees Focus on Regulatory, Educational, and Member Needs

IIAR and the Natural Refrigerant Foundation held their board meetings in Dallas in October. Gary Schrift, president of IIAR, said the meetings were well attended. During the sessions, committee chairs provided updates on the critical work they are doing.

RESEARCH COMMITTEE PROJECTS

> "The previous study outcome was well and good, but we saw an opportunity for further study that could be added to the Piping Handbook. It hopefully will provide specific knowledge about how to design valve groups to prevent hydraulic shock. The investigators expect to present it at the annual meeting."
>
> **Bill Greulich, Committee Chair**

The Research Committee is working on several important projects and looking ahead to future needs. Projects include:

Hydraulic Shock: Committee Chair Bill Greulich said this is a follow up to the previous computational fluid dynamics project completed by the same group. "The previous study outcome was well and good, but we saw an opportunity for further study that could be added to the Piping Handbook," he said. "It hopefully will provide specific knowledge about how to design valve groups to prevent hydraulic shock. The investigators expect to present it at the annual meeting."

Air Infiltration in Cold Rooms: As part of a co-funded project with ASHRAE, IIAR is looking at warm air infiltration through doorways into cold spaces. "We've earmarked funds to assist ASHRAE in this valuable work, but it is early days on this," Greulich said.

Pipe Sizing Economy Application II: This is an ongoing project looking at how pipe sizing effects energy efficiency. IIAR is planning to update the financial information in the existing software program.

Internal Relief: Based on OSHA activity within the industry, the committee is looking at commissioning a project to study release valve replacement frequency for internally relieving safety valves. "The project is looking to understand what replacement frequency fits our industry conditions.," Greulich said. "It is really important."

CO2 System Design: The committee is currently discussing a project with University of California, Berkeley on CO2 relief system design. "Since the advent of carbon dioxide refrigeration systems, we've had a lot of worry about the relief devices," Greulich said, adding that one issue is the cloud of carbon dioxide 'snow' that could potentially form in relief discharge piping, ultimately blocking it. "There is a lot of worry, we know the snow can form, but we are much less certain about the line blocking potential." The committee is currently working on the agreement details for the project, which will determine its future. If it advances, NRF will fund a PhD candidate over three years to advance CO2 system design.

ADDITIONAL COMMITTEE UPDATES

Other noteworthy committee updates from the meeting include:

CO2 Handbook Committee: The committee is targeting the publication of a CO2 handbook in mid-2024.

Safety Committee: The safety committee is finalizing the evaporator-enclosed workspace guideline.

Education Committee: The Education Committee is working on a Refrigerant Evaluator tool, which will be free for IIAR members. The committee is also planning to revisit and update the 2007 IIAR Training Guide. The guide is currently not for sale by IIAR but was used as part of the Fastport Apprenticeship Training Program development and would be important as a tool for workforce development for naturals.

AIM Act Task Force: The AIM Task Force has been closely following the development of AIM Act requirements and is considering creating a Technology Transition Task Force to assist non-natural refrigerant users on what is next in the realm of refrigerant choices and how should they evaluate and proceed with plans for replacement.

Government Relations Committee: The Occupational Health and Safety Administration (OSHA) is in the midst of revising the Process Safety Management (PSM)program, and the government relations committee plans to develop a position statement on what the committee and the industry propose. The committee also plans to train OSHA on the availability of the ammonia refrigerant release tool and calculator.

Compliance Guidelines Committee: The Ammonia Handbook update is moving forward toward publication.

International Committee: During the March 2024 IIAR Conference, the International Committee meeting has been moved to Tuesday, which means international members can now attend other committee meetings on Saturday.

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The changes help support IIAR's role as an international organization and will allow for more international involvement within IIAR committees.

Piping Sub-Committee: Major edits are underway for the Piping Manual Chapter 1.

STANDARDS COMMITTEE PROGRESS

IIAR standards have to be reviewed regularly, and work on several standards is already underway. Work includes:

IIAR 5 Subcommittee-IIAR 5 Startup of Closed-Circuit Ammonia Refrigeration Systems: Nick Nechay is the IIAR 5 subcommittee chair. Tony Lundell, senior director of standards and safety for IIAR, is the IIAR staff facilitator. Pre-public review comments are being reviewed, which addresses the standard to harmonize with IIAR 2, IIAR 4, IIAR 6, and IIAR 7. IIAR 5's first public review should be ready in early 2024.

IIAR 6 Subcommittee-IIAR 6 Standard for Inspection, Testing, and Maintenance of Closed-Circuit Ammonia Refrigeration Systems: Jeff Sutton is the IIAR 6 subcommittee chair. Lundell is the IIAR staff facilitator. Pre-public review comments about "Functionally Testing or Functional Testing" are being addressed. There are less than a dozen comments left to address, and the first public review should be ready in early 2024.

IIAR 7 Subcommittee-IIAR 7 Standard for Developing Operating Procedures for Closed-Circuit Ammonia Refrigeration Systems: Lesley Schafer is the IIAR 7 subcommittee chair. Lundell is the IIAR staff facilitator. Pre-public review comments are being addressed. The committee is focusing on the minimum requirements for operating procedures that are required for regulated (i.e., PSM/RMP systems, larger systems with 10,000 lbs. or more) ammonia refrigeration systems and non-regulated (i.e., General Duty Clause, smaller systems with less than 10,000 lbs.) ammonia refrigeration systems. The first public review should be ready in early 2024.

> "The previous study outcome was well and good, but we saw an op-portunity for further study that could be added to the Piping Handbook. It hopefully will provide specific knowledge about how to design valve groups to prevent hydraulic shock. The investigators expect to present it at the annual meeting."
>
> **Bill Greulich, IIAR Research Committee Chair**

IIAR 9 Subcommittee-IIAR 9 Standard for Minimum System Safety Requirements for Existing Closed-Circuit Ammonia Refrigeration Systems: Eric Johnston is the IIAR 9 subcommittee chair. Lundell is the IIAR staff facilitator. IIAR 9-2020 Addendum A (202x) was developed to address a scope change and an interpretation, provide a clear compliance deadline, address some simple edits, and provide a flow chart. The first Public Review started in October and ends in November. This addendum should be completed by early 2024.

IIAR HC Subcommittee-IIAR HC Safety Standard for Closed-Circuit Refrigeration Systems Utilizing Hydrocarbon Refrigerants: This standard is in development. Joseph Pillis is the IIAR HC subcommittee chair. Lundell is the IIAR staff facilitator. This standard pertains to utilizing "natural" hydrocarbon refrigerants that have zero ozone-depleting potential and very low global warming potential. The committee is reviewing and developing responses to 161 comments received during the first public review.

Several IIAR members are also ASHRAE members and have reviewed this standard in development and provided pre-public review comments and public review comments during its first review. Lundell said this standard is filling a gap for unlisted system applications that are not sufficiently addressed in ASHRAE 15.

The development of the standard will enable officials at the EPA SNAP Team to have a comprehensive safety standard to reference when considering expanding SNAP approval for hydrocarbon refrigerant applications.

"We have members on this IIAR HC Subcommittee who have the Section 608 Technician Certification and refrigeration systems utilizing hydrocarbon refrigerants that are within this standard do not deplete the ozone," Lundell said.

IIAR HC's second public review should be ready in early 2024.

FUTURE PRIORITIES

Going forward, Schrift said IIAR's general focus will be on helping with the technology transition to natural refrigerants. "Because of the many international and state-based new laws and regulations on HFC reductions, the world now has two choices—change to a new synthetic HFO or change to naturals," he said.

The technology transition to naturals involves educating users on how to safely and efficiently apply naturals, training technicians for installation and servicing, educating engineers for design, and informing end users on the advantages of naturals. It will also require technology advocacy, showing people what products exist using naturals and push industry and encouraging the government to invest in creating new products in needed use sectors, and combating the heavy anti-natural refrigerant marketing from the chemical sector.

Lundell said IIAR is strengthened by the members who volunteer their time for committees and play an essential role in the work the association does. "They are volunteers from the refrigeration industry, and they are helping us as an industry develop what we want for our destiny," he said.

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TECHNICAL PAPER #11

Simple Equations for Determining Mass Flow in Refrigeration Systems

DON FAUST, TRAINING MANAGER,
FRICK, A JOHNSON CONTROLS COMPANY

ABSTRACT

The goal of any industrial refrigeration system is to remove heat. Therefore, the total heat load is the design engineer's first calculation, which is then used to size and select the evaporators. Unfortunately, this heat load is often also applied to the sizing of other components in the system, which can result in errors. However, heat load should only be used to size components that exchange heat.

This paper introduces a methodology and develops simple equations for determining mass flows in industrial refrigeration systems. The proposed methodology involves the mass balance technique, which assumes a steady-state condition in which the sum of the mass flows into a machine or system equals the sum of the mass flows out. The mass balance technique can help quantify mass flows that may be difficult to calculate using other methods. The mass flow equations apply to any refrigerant in a typical vapor compression cycle.

Modern industrial refrigeration systems often employ multiple temperature and pressure levels to maintain various conditions in processing and storage facilities. Mass balances enable the accurate sizing of various pieces of equipment, and this technique can reveal strategies for saving energy and initial cost.

Introduction

When designing an industrial refrigeration system, the first calculation determines how much heat must be removed and at what temperature. The evaporator load is the first "hard number" a system designer calculates, and the rest of the system follows from there.

The ton of refrigeration (TR) unit is used to describe a heat transfer rate, particularly applicable to evaporators. Sizing all the equipment in an industrial refrigeration system based on the evaporator heat load (i.e., one number does it all) would be convenient. Often, designers do precisely that: select non-heat exchanging equipment using a rate of heat exchange.

The sizing tables published by manufacturers imply that evaporator load is a valid method for sizing all industrial refrigeration equipment. Virtually every component in a refrigeration system has a table or chart showing its "capacity" in TR (or kW). Pipes, vessels, pumps, compressors, and valves have manufacturer- and industry-published capacities in units of heat transfer. These tables include footnotes, typically in small print, listing the assumptions, which should prevent the designer from using the wrong units of measure to size their equipment.

By examining the equipment in an industrial refrigeration system, the units for sizing the equipment are clearly essential to the equipment's function. For example, a compressor can be viewed as a gas volume reduction device, revealing the fundamental unit for compressors—volumetric flow rate. Vessels for separation can be considered fat spots in the pipe where the vapor is slowed down. Thus, volumetric flow is a proper determiner for vessel size. Note that vessels may also require a holding capacity independent of liquid–vapor separation requirements.

Proper Units for Selecting Equipment

Equipment	Unit of Measure
Evaporator	Refrigeration heat load
Condenser	Compressor heat load
Compressor	Volumetric flowrate of suction vapor
Vessel	Volumetric flowrate and storage volume
Expansion Device	Mass or volumetric flowrate/quality
Pipe and Valve	Mass or volumetric flowrate/quality
Pump	Mass or volumetric flowrate

In an industrial refrigeration system, the proper units for most of the equipment are not related to the heat transfer occurring in the evaporators. A mass balance reveals the mass flows for every piece of equipment in the system, which can be converted into the proper units of measure to size each component.

Mass Balance Equation

$$\sum Mass\ flows\ in = \sum Mass\ flows\ out$$

The problem-solving technique of mass balance centers around the concept that mass flow in equals mass flow out at steady-state conditions for a system or sub-system. In a chemical process, numerous factors can change the physical state of the refrigerant, which significantly affects the volume, but the mass flows must still balance. Every part of the system has a mass flow of refrigerant in and out, and the sum of the flows into and out of each piece of equipment must be equal. Mass balance applies to any single piece or group of pieces of equipment. Mass in must equal mass out under steady-state conditions.

Are Refrigeration Systems Steady-state?

Many examples of non–steady-state circumstances are related to refrigeration systems, including spiral freezers starting up in the morning, condensers that fill with liquid, and receivers that run dry. Do these empirical observations disprove the steady-state assumption for refrigeration systems? The answer is both yes and no. Yes, the steady-state assumption does not account for system upsets, making it invalid for brief periods. However, the longer the duration, the more valid the steady-state assumption. A mass imbalance can only be present for a short period for the steady-state assumption to apply, which is the case in industrial refrigeration systems.

Flash Gas Problem

One issue with using evaporator load to size other equipment is accounting for the non-useful work of flash gas (FG). This is not an issue with single-temperature systems, as flash gas is typically considered in the manufacturers' catalog ratings. When the system has multiple suction temperatures and each level removes FGs for the lower temperature levels, the system cannot be accurately sized using evaporator load.

Most industrial refrigeration systems have multiple suction temperatures, and how they handle FG is based on system efficiency. Performing a system mass flow balance is an effective way to account for FG in a multiple-temperature system properly.

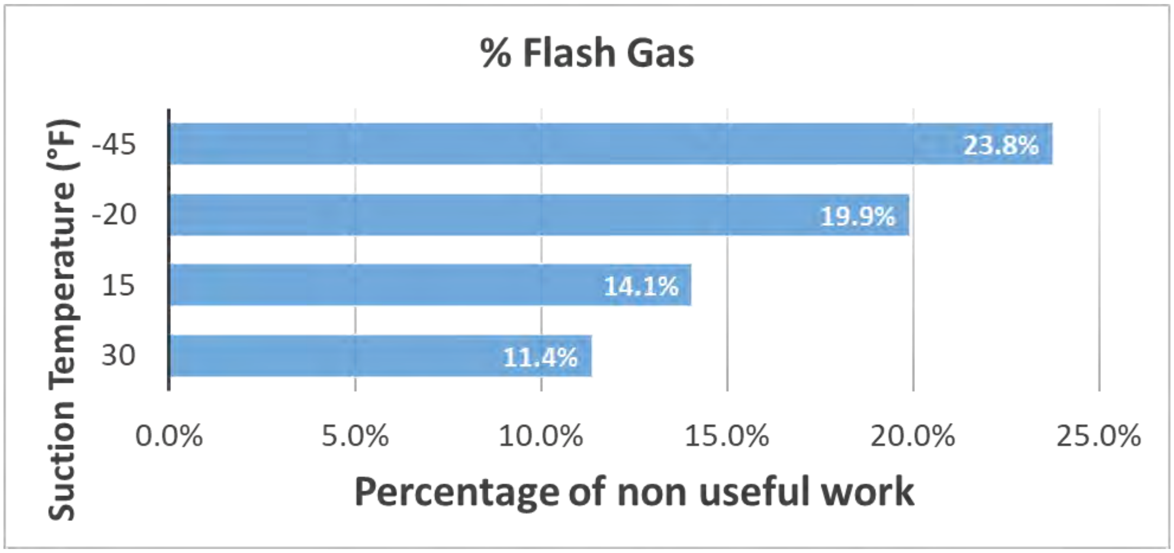


Figure 1. Flash Gas Mass Percentage

FG is not an insignificant load. Figure 1 shows that FG accounts for 1/8 to 1/4 of the total mass flow to the compressors of a refrigeration system, depending on the suction temperature, highlighting the need for mass balances. FG is the next major load after the refrigeration load itself, and it is too significant to be subjected to guesses. When multi-temperature systems are used, a mass balance can accurately calculate how much FG occurs at each temperature level.

The condensing temperature used in these calculations is 85°F. While 95°F is commonly used to size condensers, it is based on 0.4% of one day. Most systems run at around 85°F, condensing most of the time, so this temperature is sufficient for analyzing typical, not worst-case, operation.

Thermodynamic Calculations

Latent heat of evaporation, FG, and net refrigerating effect (NRE) are terms that are familiar to the refrigeration engineer. Liquid cooling (LC) is a term used to quantify the FG "load." Figure 2 depicts the LC, RE, and latent heat terms. Note that all thermodynamic equations are listed in the appendix.

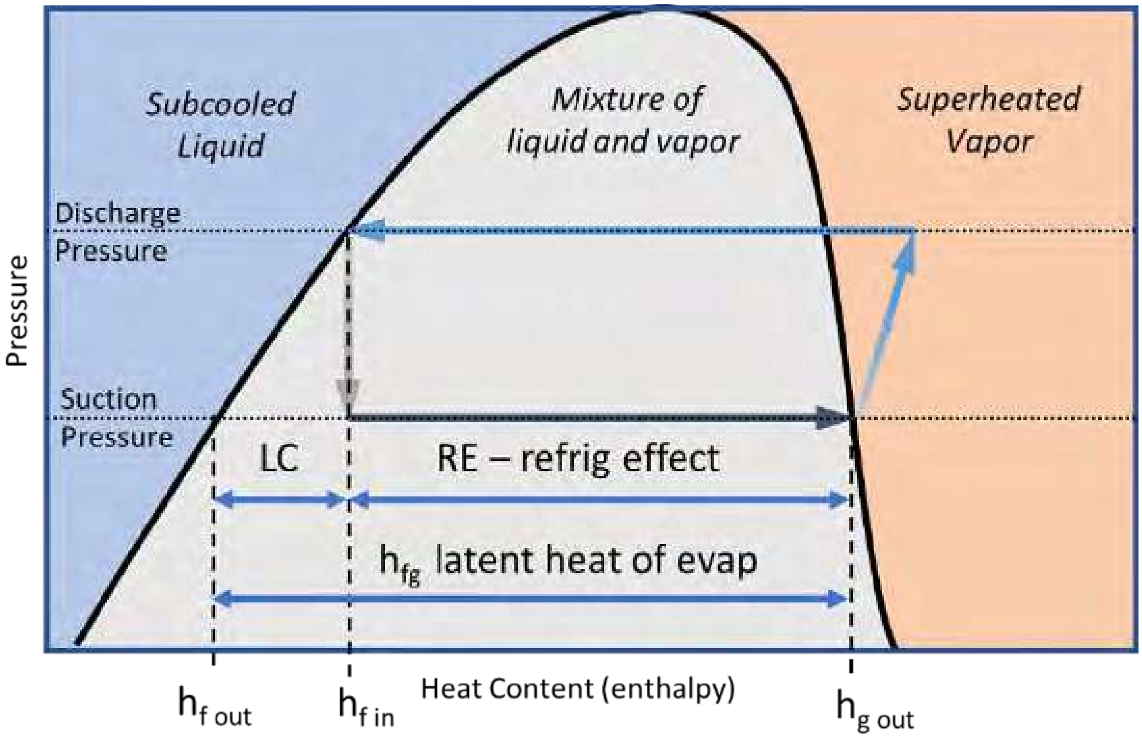


Figure 2. Pressure Enthalpy Diagram Showing LC and RE

Latent Heat of Evaporation

The latent heat of evaporation h_{fg} is the difference in enthalpy between saturated liquid and saturated vapor at a constant temperature. This value, often listed in thermodynamic tables, can be calculated by subtracting the enthalpy of the saturated liquid h_f from the enthalpy of the saturated vapor h_g at the temperature and pressure under consideration:

EQ (1) $$h_{fg} = h_f \cdot$$

Net Refrigerating Effect

The NRE is the difference in enthalpy between the entering liquid h_{fin} and the saturated vapor h_{gout} in the process under consideration, as shown in EQ (2). The absolute value of this term is commonly used.

$$\text{EQ (2)} \qquad NRE = h_{fin} - h_{gout}$$

Liquid Cooling

Work, in the form of mechanical cooling, occurs when the temperature of a liquid refrigerant decreases within a closed system. For example, warm liquid entering a cold evaporator must be cooled to its saturation temperature. This cooling load, called LC, is the difference between the entering liquid's enthalpy h_{fin} and the leaving liquid's enthalpy h_{fout}:

$$\text{EQ (3)} \qquad LC = h_{fin} - h_{fout}$$

Flash Gas

FG is the vapor generated when cooling the incoming liquid to the saturated temperature in the process being examined. The FG calculation requires NRE and LC. The FG load is the product of the mass flow rate of the liquid L and the LC enthalpy difference. The FG mass flow is simply equal to that load divided by the latent heat of evaporation:

$$\text{EQ (4)} \qquad FG = \frac{(L \times LC)}{h_{fg}}$$

Breaking Down Latent Heat of Evaporation

Evaporation always occurs at saturation. However, not all processes in a refrigeration system occur with saturated liquid and saturated vapor. For example, if warm liquid enters a cold evaporator, the liquid must cool to saturation before it can evaporate, known as LC. The net thermodynamic result of cooling the liquid to saturation with subsequent evaporation is called the NRE. The latent heat of evaporation is considered as the sum of the NRE and the LC:

$$\text{EQ (5)} \qquad h_{fg} = h_f - h_g = NRE + LC$$

Mass Flow for Evaporators

Evaporator mass flows vary depending on the type of evaporator feed being used. Two assumptions are made: all evaporators take in liquid, and what exits is either a vapor or a mixture of vapor and liquid. Figure 3 shows an evaporator mass flow diagram.

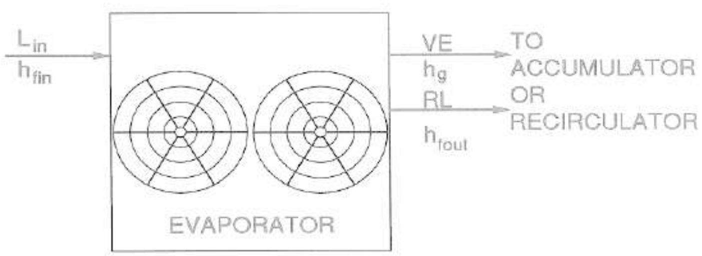


Figure 3. Evaporator Mass Flow Diagram.

L_{in} Mass flow rate of liquid into the evaporator (lb/min)

h_{fin} Enthalpy of the liquid going into the evaporator (BTU/lb)

VE Vapor generated by the evaporator (lb/min)

h_g Enthalpy of the vapor generated by the evaporator (BTU/lb)

RL Returned liquid coming out of the evaporator (lb/min)

h_{fout} Enthalpy of the liquid exiting the evaporator (BTU/lb)

Two scenarios are examined:

DX Feed

Liquid enters the evaporator through a direct expansion (DX) device, and it is flashed down to the evaporating temperature. The vapor exiting the evaporator is dry. All the liquid fed to the evaporator evaporates, leaving no returned liquid (RL) (i.e., RL = 0).

Overfed (Pumped or Flooded) Feed

The liquid is flashed down to the evaporator temperature in the recirculator, then pumped to the unit. The liquid enters at the evaporation temperature; therefore, no FG is generated at the evaporator. The vapor exiting the evaporator carries the overfed liquid.

DX Feed Evaporators

No RL is present because the suction coming out of a DX evaporator is dry. For calculation purposes, the expansion device is considered to be a part of the evaporator. For DX, the recirculation ratio n is one.

The vapor generated by the evaporator is the refrigeration load divided by the NRE.

EQ (6) $$VE_{DX} = \frac{W}{NRE}$$

where W is the refrigeration load (BTU/min). To convert TR to BTU/min, multiply by 200.

Most DX systems utilize superheat in the vapor to control the amount of liquid feed. This superheat performs useful work in cooling. To properly account for the superheat's contribution, use h_g for the superheated condition in the NRE calculation. However, if the superheated vapors meet saturated liquid later in the system, such as in a wet return pipe or a vessel, the superheated vapors are cooled to saturation. In this case, the net effect to the system would be the same, using the enthalpy for saturated gas at evaporation. The examples for mass balance use this approximation—saturated conditions are used at the outlet of the DX evaporator.

The liquid supplied to the evaporator is

EQ (7) $$L_{in} = n \times VE_{DX}$$

For DX evaporators, $n = 1$. Therefore, EQ (7) becomes

EQ (8) $$L_{DX} = VE_{DX}$$

Note that DX evaporators typically receive their liquid from one vessel and return the vapor to another. For example, the high-pressure receiver feeds the liquid to the evaporator, and the vapor flows to the accumulator. This information is critical when doing vessel mass balances. Most DX evaporators feed from the high-pressure receiver, but some may feed from a different source, and their liquid feed must be added to the liquid flowrate out L_{out} for the vessel supplying the liquid.

Overfed Evaporators (Pumped or Flooded)

Overfed evaporators feed more liquid than they evaporate. Often, this liquid is fed to the evaporator as a saturated liquid—the FG is taken off in the recirculator vessel, and the liquid is pumped to the evaporator. In these cases, the evaporator can use the entire latent heat of evaporation rather than just the NRE. The downside to this approach is that the return piping must carry both the vapor generated by the evaporator and the overfed liquid.

Circulation Ratio

The industrial refrigeration industry uses many terms for circulation ratio, including overfeed rate, overfeed ratio, recirculation ratio, circulating number, and circulating rate. However, the definition of the concept remains the same in textbooks and handbooks, as illustrated in Figure 4.

Page 302 of Will Stoecker's "Industrial Refrigeration Handbook" defines the circulation ratio n as

$$n = \frac{refrigerant\ flowrate\ supplied\ to\ the\ evaporator}{flowrate\ of\ refrigerant\ vaporized}$$

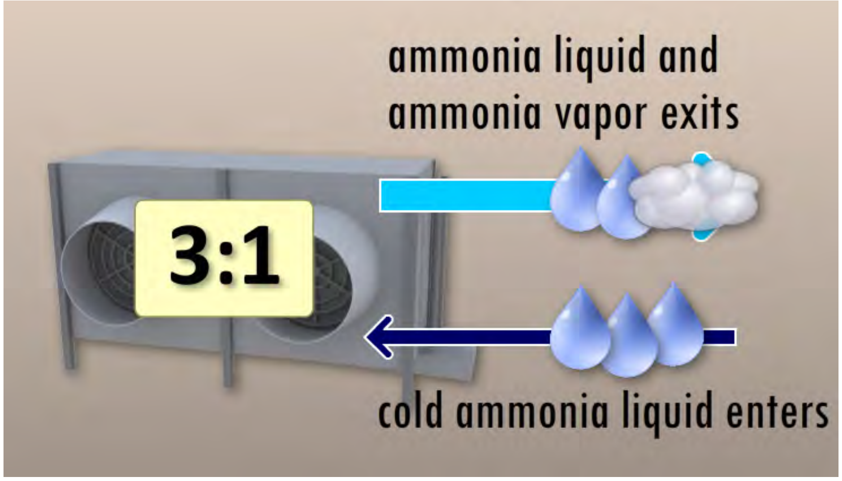


Figure 4. Circulation ratio n.

The ASHRAE Refrigeration Handbook, 1990, page 2.3, states: “In a liquid overfeed system; the mass ratio of liquid pumped to the amount of vaporized liquid is the circulating number or rate.” The circulation ratio defines the quality of the refrigerant at the outlet of the evaporator. A vapor quality of 50% implies a 2:1 circulation ratio. Likewise, if the vapor quality is 33%, the circulation ratio is 3:1. This simple ratio of the amount of vapor generated to the amount of liquid fed to the evaporator is the inverse of the vapor quality.

One difference between CPR and pumped systems is the temperature of the liquid fed to the evaporators. In a pumped system, the liquid is at its saturation temperature in the recirculator, where the pump pressurizes it (in effect making it a subcooled liquid) and pushes the saturated liquid out to the evaporators.

The vapor generated by the evaporator (see Figure 3) is calculated as

EQ (9) $$VE_{OF} = \frac{W}{NRE}$$

Equation (9) applies to flooded or recirculated feeds. However, for a pumped recirculated feed, the NRE is the same as h_{fg}. Thus, for recirculated loads, EQ (9) can be simplified to

$$\text{EQ (10)} \quad VE_{OF} = \frac{W}{h_{fg}} \text{ (Recirculated only)}$$

For cases in which the pumped or pressure-fed liquid is not at saturated conditions for the evaporator (i.e., in CPR systems), using the NRE (EQ (9)) is more appropriate, even though $NRE = h_{fg}$ for many applications.

The liquid supplied to the evaporator is calculated as

$$\text{EQ (11)} \quad L_{in\,OF} = n \times VE_{OF}$$

Additionally, the returned (overfed) liquid (RL) is calculated as

$$\text{EQ (12)} \quad RL_{OF} = (n - 1) \times VE_{OF}$$

No load comes from the overfed liquid in a recirculated system. However, in CPR systems, the overfed liquid creates a refrigeration load, which must be included in the calculations.

Vessel Mass Flow

Mass balances can be applied to any component in the industrial refrigeration system. However, the vessels are the critical components when solving the mass flows for the system. The vessels are central in terms of flow—they receive the mass flows from the evaporators, they often produce FG, and the compressors pull vapor from the vessels. The vessels in the system require an understanding of where FG is removed so that the compressors can be sized properly.

The mass flow *VE* of vapor generated by the evaporators is required before achieving a system mass balance. This mass flow, which performs useful work, accounts for 80% of the vapor generated by the system. The remaining 20% of vapor is FG, which does not do useful work.

The most efficient way to organize a system is to have the liquid from the condensers flow through each temperature in the system successively. Higher-temperature vessels feed the liquid to the next lower-temperature vessel. That way, the liquid is flashed off in steps until it gets to the lowest temperature in the system. Note that the liquid fed to the −35°F vessel comes from the +25°F intercooler. The liquid from the HP receiver is first cooled to +25°F, then to −35°F.

The system shown in Figure 5 is a two-stage intercooled system. This generalized method applies to any refrigerant and both single-and two-stage systems. In a single-stage system, the booster discharge (BD) mass flows are zero. For a two-stage intercooled system, the system may look like Figure 5.

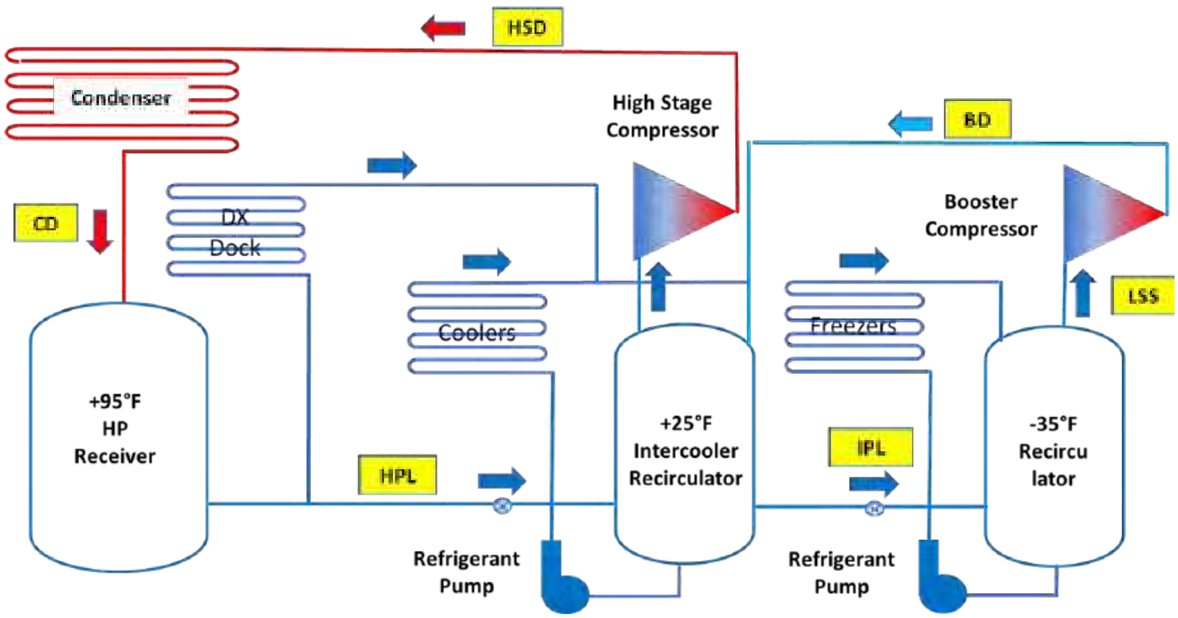


Figure 5. Typical Two-stage System.

Vessel Mass Flow Equations

For any piece of equipment, the following must be true:

$$\sum Mass\ flows\ in\ = \sum Mass\ flows\ out$$

The methodology described herein applies to any vessel (except for a CPR with cold liquid return). This generalized approach includes a provision for an intercooler; if the vessel does not do intercooling, the corresponding parameters are zero.

The sum of all the flows in minus those out equals zero. The mass flows are listed below and illustrated in Figure 6:

BD	in	Superheated vapor from the booster compressors
VE_{OF}	in	Vapor returned from overfed evaporators
VE_{DX}	in	Vapor returned from DX evaporators
RL	in	Liquid returned from overfed evaporators
L_{in}	in	Liquid makeup
V_{BD}	out	Vapor generated by desuperheating booster discharge plus BD
VC	out	Dry vapor to the compressor
PL	out	Pumped liquid to evaporators
L_{out}	out	Pressure feed liquid to another vessel

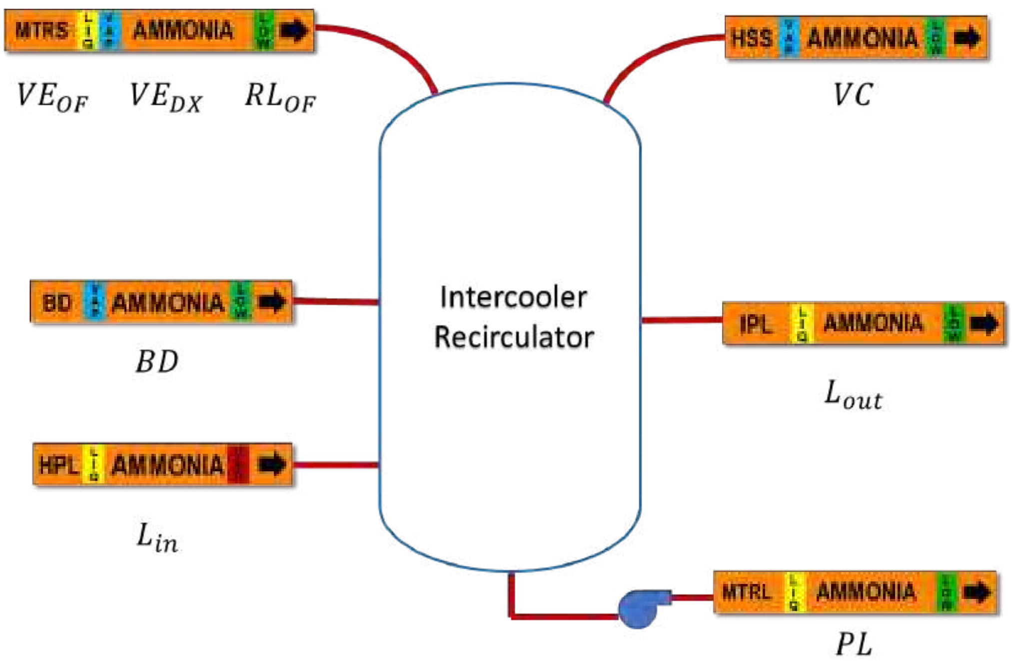


Figure 6. Vessel Mass Flow Variables.

The vapor mass flow *VE* generated in the evaporators and the liquid makeup L_{in} to the vessel are independent of the overfeed rate. The overfeed rate is introduced to the calculations for pumping rate *PL* and the amount of liquid returned *RL* in the wet suction header. The vapor flow to the compressor *VC* is simply the sum of *VE*, the cooling performed on the discharge gases V_{dsh}, *BD*, and any flash loads.

Thermodynamically, four enthalpies are of concern:

h_{fin} Entering liquid enthalpy (HPL)

h_f Saturated liquid enthalpy at vessel pressure

h_g Saturated vapor enthalpy at vessel pressure

h_{BD} Booster discharge superheated vapor enthalpy at vessel pressure

The first step in solving for mass flow is to use EQ (2) and EQ (3) to determine NRE and LC.

Intercoolers

If the vessel under consideration is an intercooler, then EQs (13)–(16) apply. If the vessel is not an intercooler, these values are zero.

For an intercooler, the high-stage compressors must recompress the low-stage mass flow and take in the vapor generated by desuperheating the BD gases. For this example, the BD gas is assumed to be desuperheated to saturated conditions by using the saturated enthalpy h_g. If this is not the case, use the expected enthalpy at the gas condition.

Booster Gas Load to High Stage

The booster gas load considers the enthalpy difference between the superheated BD gas and the saturated gas:

$$\text{EQ (13)} \quad DSH = (h_{BD} - h_g)$$

Multiply the result of EQ(13) by the mass flow to obtain the load:

$$\text{EQ (14)} \quad Booster\ Load = DSH \times BD$$

where *BD* is the mass flow from the low-stage compressors (lb/min or kg/min). Vapor generated by desuperheating is the booster load divided by the NRE.

$$\text{EQ (15)} \quad V_{dsh} = \frac{DSH \times BD}{NRE}$$

For the intercooler, the NRE is the enthalpy difference between the saturated vapor in the intercooler and the makeup liquid (typically HPL). The mass flow from the BD is then added to the desuperheating load for the total BD load.

$$\text{EQ (16)} \quad V_{BD} = \frac{DSH \times BD}{NRE} + BD$$

Vessel Overall Mass Balance

The first intercooler equation is a mass balance. The masses entering the vessel are L_{in}, VE, RL, and BD. The masses leaving the vessel are the pumped liquid PL, L_{out}, and VC. The sums of mass into and out of an intercooler should be equal.

$$\text{EQ (17)} \quad L_{in} + VE_{OF} + VE_{DX} + RL + BD = PL + L_{out} + VC$$

Pumped Liquid

The mass flow of pumped liquid PL going out, in terms of mass flow, equals the mass flow of VE plus that of the RL:

$$\text{EQ (18)} \quad PL = VE_{OF} + RL$$

Vapor to the Compressor

The load to the compressors is the sum of VE, the FG mass flow from the incoming liquid, and the BD load.

$$\text{EQ (19)} \quad VC = VE_{DX} + VE_{OF} + FG + V_{BD}$$

Using EQ (4), for FG, EQ (19) can be rewritten:

$$\text{EQ (20)} \quad VC = VE_{DX} + VE_{OF} + V_{BD} + L_{in} \times \frac{LC}{h_{fg}}$$

Makeup Liquid

The amount of makeup liquid is equal to the amount of vapor evaporated by the overfed evaporators, the desuperheating vapor to the intercooler, the FG generated by the makeup liquid, and any liquid fed downstream (L_{out}).

$$\text{EQ (21)} \quad L_{in} = VE_{OF} + V_{dsh} + L_{in} \times \frac{LC}{h_{fg}} + L_{out}$$

No DX loads need to be considered, so only the evaporated portion of the evaporator load is included in the liquid feed.

Since L_{in} exists on both sides of EQ (21), solving EQ (21) for L_{in} produces EQ (22):

$$\text{EQ (22)} \quad L_{in} = \frac{VE_{OF} + V_{dsh} + L_{out}}{1 - \left(\frac{LC}{h_{fg}}\right)}$$

Pressure Feed to Downstream Vessels

Solving for liquid out L_{out} is not possible. The value of L_{out} must be known before solving the rest of the equations. Thus, the solution begins at a vessel in which L_{out} is known—**at the lowest-temperature vessel in the system**, where L_{out} is zero.

In other words, all analyses must start with the lowest-temperature vessel in the system and move up from there. The mass flow L_{in} for the lowest-temperature vessel equals L_{out} for the next lowest-temperature vessel, and so on.

This model assumes that DX liquid comes from the high-pressure receiver. If the DX feed liquid comes from another source (i.e., a different vessel), then simply add that amount of liquid to the L_{out} for that vessel.

Vessel Inflows and Outflows

Figures 7 and 8 illustrate the vessel inflow and outflow equations.

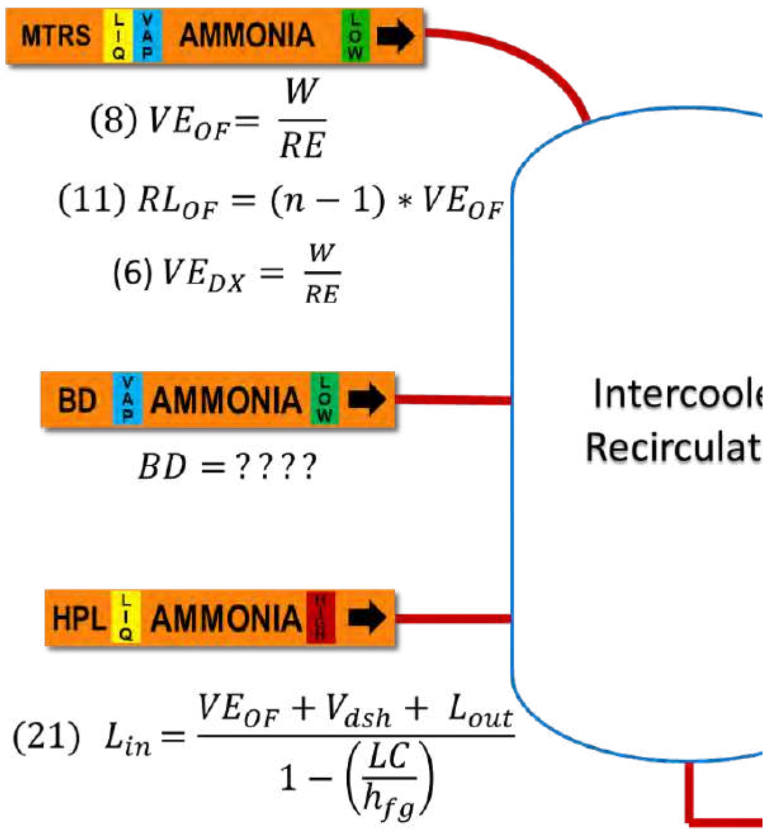


Figure 7. Vessel Inflow Equations.

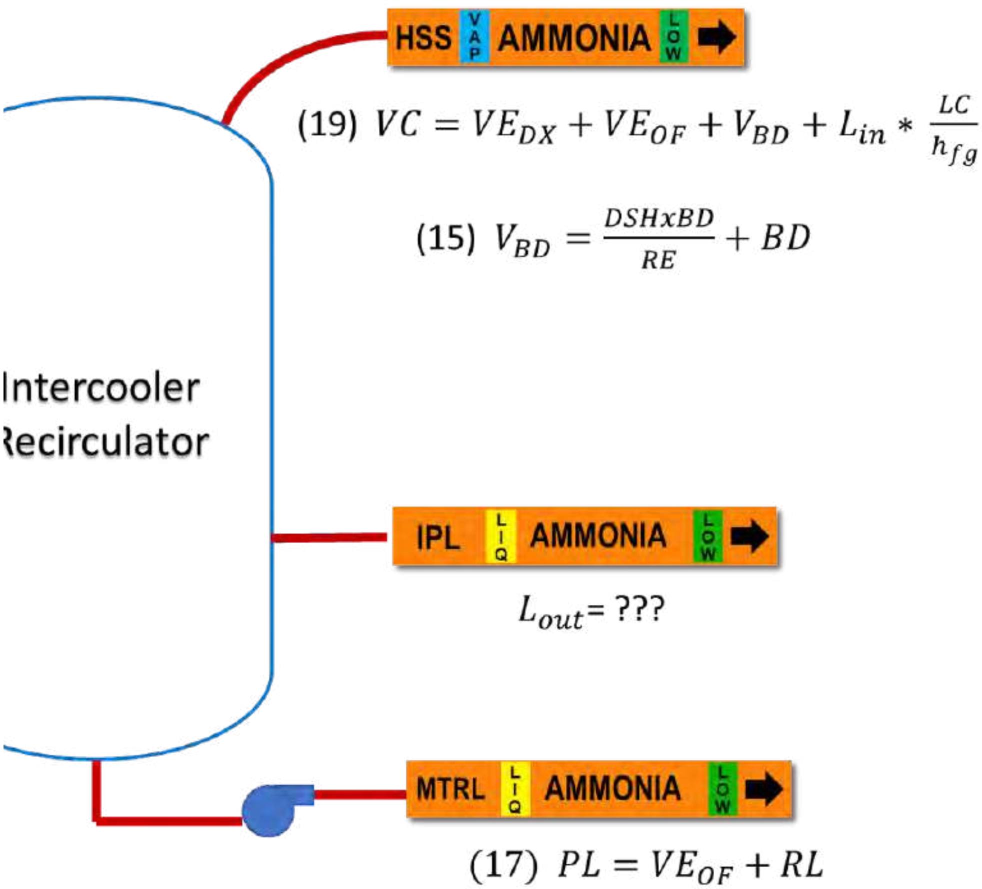


Figure 8. Vessel Outflow Equations.

Mass Flows (lb/min or kg/min)

BD	in	Superheated vapor from the booster compressors
VE_{OF}	in	Vapor returned from overfed evaporators
VE_{DX}	in	Vapor returned from DX evaporators
RL	in	Liquid returned from overfed evaporators
L_{in}	in	Liquid makeup

V_{BD}	out	Vapor generated by desuperheating booster discharge plus BD
VC	out	Dry vapor to the compressor
PL	out	Pumped liquid to evaporators
L_{out}	out	Pressure feed liquid to another vessel

Other Terms

n	Circulating ratio
W	Refrigeration Load
RE	Refrigerating Effect
h_{fg}	Latent Heat of Evaporation
DSH	Desuperheating enthalpy difference

Applying Mass Balances to Systems

To perform the mass balance, the following information is needed:

- Evaporator loads
- Respective system temperatures and pressures
- Style of feed for the sets of evaporators

Then, using the thermodynamic properties of the refrigerant, the rest of the calculations can be performed.

A multiple-temperature system consisting of four temperature levels, including a two-stage component for the low low–temperature load, will be analyzed. The evaporator loads are as follows:

Evaporator Loads	Temp (°F)	Load (TR)	Temp (°C)	Load (kW)
High-temperature	30	150	− 1.11	527.55
Medium-temperature	15	600	− 9.44	2110.2
Low-temperature	− 20	200	− 28.89	703.4
Low low–temperature	− 45	500	− 42.78	1758.5

The appendix shows the results of a spreadsheet analysis of the system using both imperial (IP) and SI units. Note that the analysis must begin with the lowest-temperature vessel in the system and move up from there.

Conclusion

Mass balances are simple to perform, requiring only an hour or two of spreadsheet programming, and these equations can be used to solve for any refrigerant at any temperature. Unfortunately, although easy to do, many systems are designed without mass balances. However, if the user carefully reads the fine print on the ratings, a system can be designed using evaporator loads only with near-accurate results. For many industrial refrigeration systems, near-accuracy is not sufficient, especially when a mass balance can be performed to obtain more realistic loads in the system. With computers and spreadsheets available, every system should have a mass balance.

Appendix

Mass Balance Example—IP Units

The mass balance example for this system consists of four refrigeration levels. The receiver is assumed to be at normal operating conditions (85°F condensing). The loads are shown in Table A1:

Table A1. Mass Balance Inputs Using IP Units.

Vessel	Temp (°F)	Load (TR)	
High-temp	+ 30	150	DX
Medium-temp	+ 15	600	LR 1.2:1
Low-temp	− 20	200	LR 2:1
Low low–temp	− 45	500	LR 4:1

Note that the low low–temperature system is two-stage, and it discharges into the high-temperature vessel.

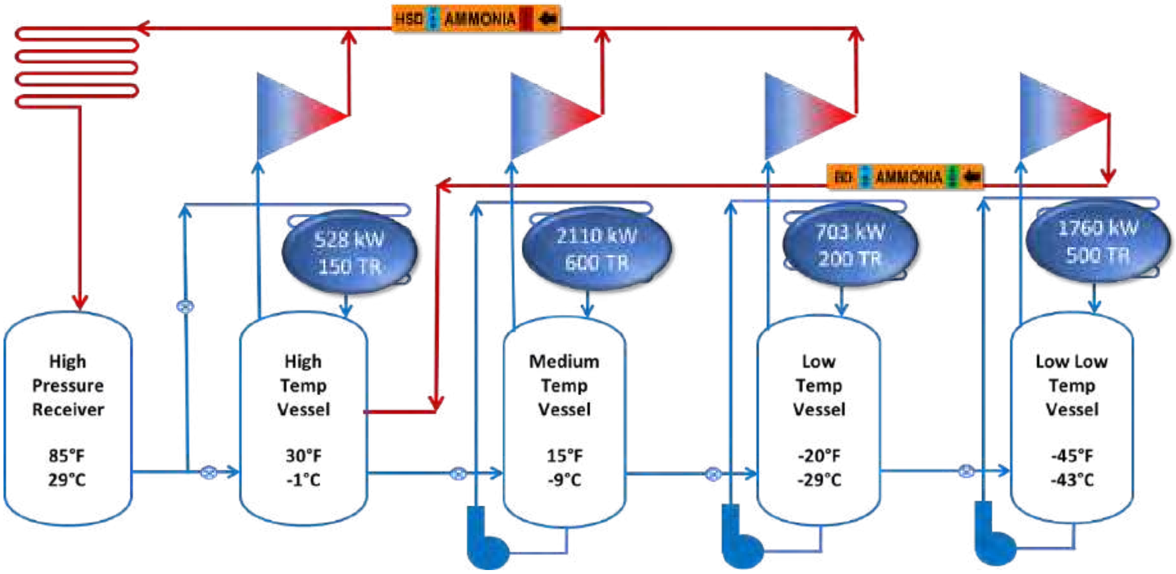


Figure A1. Industrial Refrigeration System Mass Balance Illustration.

The thermodynamic properties of the refrigerant at the selected design temperatures (courtesy of FRICK CoolWare) are shown in Table A2. Figure A2 shows a snapshot of the spreadsheet program solving the mass balance with IP units.

Table A2. Thermodynamic Properties for the Refrigerant in IP units.

Refrigerant Properties (R717)		Low Low Temp		Low Temp		Medium Temp		High Temp		Condensing	
T	(°F)	-45	-45	-20	-20	15	15	30	30	85	85
P	(psia)	8.9	8.9	18.3	18.3	43.1	43.1	59.7	59.7	166.4	166.4
V	(ft³/lbm)	0.023	28.658	0.024	14.682	0.025	6.56	0.025	4.822	0.027	1.8
H	(btu/lbm)	65.5	666.1	92.1	675.2	130	686.4	146.4	690.6	208.3	701.4
S	(btu/lbm-°R)	0.171	1.62	0.233	1.56	0.316	1.488	0.35	1.461	0.469	1.374
U	(btu/lbm)	65.4	618.8	92	625.6	129.8	634.1	146.1	637.3	207.5	646
X		0	1	0	1	0	1	0	1	0	1
Mw	(g/mol)	17.03	17.03	17.03	17.03	17.03	17.03	17.03	17.03	17.03	17.03
DewT	(°F)	-45	-45	-20	-20	15	15	30	30	85	85
Density	(lbm/ft³)	43.27	0.03	42.21	0.07	40.66	0.15	39.96	0.21	37.22	0.56

Thermo Properties							Notes
System Temp	**85**	**30**	**15**	**-20**	**-45**	**°F**	
Pressure	166	60	43	18	9	**psia**	
hf (bubble point)	208	146	130	92	66	BTU/#	
hg (dew point)	701	691	686	675	666	BTU/#	
vapor volume	2	5	7	15	29	ft3/#	
hg @ 165°F		768	770			BTU/#	
hfg (LHE)	493	544	556	583	601	BTU/#	EQ (1)
RE		482	540	545	574	BTU/#	EQ (2)
LC		62	16	38	27	BTU/#	EQ (3)
Evaporator Load							
System Temp	**85**	**30**	**15**	**-20**	**-45**	**°F**	
Recirculated Loads		0	600	200	500	TR	
W		0	120000	40000	100000	BTU/min	(TR x 200)
n		0.0	1.2	2.0	4.0	:1 overfeed	
DX Loads		150	0	0	0	TR	
W		30000	0	0	0	BTU/min	(TR x 200)
Sum of Evap Loads		**30,000**	**120,000**	**40,000**	**100,000**	BTU/min	
Booster Load							
System Temp	**85**	**30**	**15**	**-20**	**-45**	**°F**	
BD		182	0			#/min	
DSH		78	84			BTU/#	EQ (12)
Booster load		14160	0			BTU/min	EQ (13)
Vdsh		29	0			#/min	EQ (14)
Vbd		211	0			#/min	EQ (15)
Vessel Inlets							
System Temp	**85**	**30**	**15**	**-20**	**-45**	°F	
VE OF		0	222	73	174	#/min	EQ (8)
VE DX		55	0	0	0	#/min	EQ (6)
VE Total		**55**	**222**	**73**	**174**	#/min	
BD		182	0			#/min	
RL		0	44	73	523	#/min	EQ (11)
Lin		609	511	273	182	#/min	EQ (20)
Vessel Outlets							
System Temp	**85**	**30**	**15**	**-20**	**-45**	°F	
PL		0	267	147	697	#/min	EQ (17)
Lout	609	511	273	182	0	#/min	
VC		336	237	91	182	#/min	EQ (19)
Sum of all flows		0	0	0	0	#/min	
Compressor Sizing							
System Temp	**85**	**30**	**15**	**-20**	**-45**	°F	
VC		336	237	91	182	#/min	
Volumetric flow		1619	1557	1338	5224	cfm	
Total CFM	**9738**						

Figure A2. Mass Balance Spreadsheet for the Example with IP Units.

Mass Balance Example—SI Units

This mass balance example is for the same system consisting of four refrigeration levels. The receiver is assumed to be at normal operating conditions (29°C°F condensing). The loads are shown in Table A2:

Table A3. Mass Balance Inputs Using IP Units.

Vessel	Temp (°C)	Load (kW)	
High-temp	− 1.1	528	DX
Medium-temp	− 9	2110	LR 1.2:1
Low-temp	− 29	703	LR 2:1
Low low–temp	− 43	1760	LR 4:1

The thermodynamic properties of the refrigerant at the selected design temperatures (courtesy of FRICK CoolWare) are shown in Table A4:

Table A4. Thermodynamic Properties for the Refrigerant in SI units.

Refrigerant Properties (R717)		Low Low Temp		Low Temp		Medium Temp		High Temp		Condensing	
T	(°C)	-42.8	-42.8	-28.9	-28.9	-9.4	-9.4	-1.1	-1.1	29.4	29.4
P	(bara)	0.62	0.62	1.26	1.26	2.97	2.97	4.12	4.12	11.47	11.47
V	(m^3/kg)	0.00144	1.78903	0.00148	0.91658	0.00154	0.40949	0.00156	0.30103	0.00168	0.11236
H	(kJ / kg)	152.3	1549.4	214.2	1570.6	302.3	1596.6	340.5	1606.2	484.6	1631.5
S	(kJ / kg-K)	0.716	6.781	0.977	6.53	1.323	6.231	1.465	6.117	1.962	5.753
U	(kJ / kg)	152.2	1439.2	214	1455.1	301.8	1474.9	339.9	1482.3	482.6	1502.6
X		0	1	0	1	0	1	0	1	0	1
Mw	(g/ mol)	17.03	17.03	17.03	17.03	17.03	17.03	17.03	17.03	17.03	17.03
DewT	(°C)	-42.8	-42.8	-28.9	-28.9	-9.4	-9.4	-1.1	-1.1	29.4	29.4
Density	(kg/ m^3)	693.1	0.6	676.2	1.1	651.3	2.4	640.1	3.3	596.2	8.9

Thermo Properties							Notes
System Temp	29	-1	-9	-29	-43	°C	
Pressure	11.470	4.120	2.970	1.260	0.620	bara	
hf (bubble point)	485	341	302	214	152	kJ/kG	
hg (dew point)	1632	1606	1597	1571	1549	kJ/kG	
vapor volume	0.11236	0.30103	0.40949	0.91658	1.78903	m3/kG	
hg @ 74°C		1786	1791			kJ/kG	
hfg (LHE)	1147	1266	1294	1356	1397	kJ/kG	EQ (1)
RE		1122	1256	1268	1335	kJ/kG	EQ (2)
LC		144	38	88	62	kJ/kG	EQ (3)
Evaporator Load							
System Temp	29	-1	-9	-29	-43	°C	
Recirculated Loads		0	2110	703	1759	kW	
W		0	126612	42204	105510	kJ/min	(kW x 60)
n		0.0	1.2	2.0	4.0	:1 overfeed	
DX Loads		527.6	0	0	0	kW	
W		31653	0	0	0	kJ/min	(kW x 60)
Sum of Evap Loads		31,653	126,612	42,204	105,510	kJ/min	
Booster Load							
System Temp	29	-1	-9	-29	-43	°C	
BD		83	0			kG/min	
DSH		180	194			kJ/kG	EQ (12)
Booster load		14867	0			kJ/min	EQ (13)
Vdsh		13	0			kG/min	EQ (14)
Vbd		96	0			kG/min	EQ (15)
Vessel Inlets							
System Temp	29	-1	-9	-29	-43	°C	
VE OF		0	101	33	79	kG/min	EQ (8)
VE DX		25	0	0	0	kG/min	EQ (6)
VE Total		25	101	33	79	kG/min	
BD		83	0			kG/min	
RL		0	20	33	237	kG/min	EQ (11)
Lin		276	232	124	83	kG/min	EQ (20)
Vessel Outlets							
System Temp	29	-1	-9	-29	-43	°C	
PL		0	121	67	316	kG/min	EQ (17)
Lout	276	232	124	83	0	kG/min	
VC		152	108	41	83	kG/min	EQ (19)
Sum of all flows		0	0	0	0	kG/min	
Compressor Sizing							
System Temp	29	-1	-9	-29	-43	°C	
VC		152	108	41	83	kG/min	
Volumetric flow		46	44	38	148	m3/min	
Total Volume Flow	276					m3/min	

Figure A3. Mass Balance Spreadsheet for the Example with SI Units.

List of Equations

(1) $h_{fg} = h_f - h_g$

(2) $NRE = h_{fin} - h_{gout}$

(3) $LC = h_{fin} - h_{fout}$

(4) $FG = \frac{(L \times LC)}{h_{fg}}$

(5) $h_{fg} = h_f - h_g = NRE + LC$

(6) $VE_{DX} = \frac{W}{NRE}$

(7) $L_{DX} = VE_{DX}$

(8) $VE_{OF} = \frac{W}{NRE}$

(9) $VE_{OF} = \frac{W}{h_{fg}}$ (Recirculated only)

(10) $L_{in\,OF} = n \times VE_{OF}$

(11) $RL_{OF} = (n - 1) \times VE_{OF}$

(12) $DSH = (h_{BD} - h_g)$

(13) $Booster\ Load = DSH \times BD$

(14) $V_{dsh} = \frac{DSH \times BD}{NRE}$

(15) $V_{BD} = \frac{DSH \times BD}{NRE} + BD$

(16) $L_{in} + VE_{OF} + VE_{DX} + RL + BD = PL + L_{out} + VC$

(17) $PL = VE_{OF} + RL$

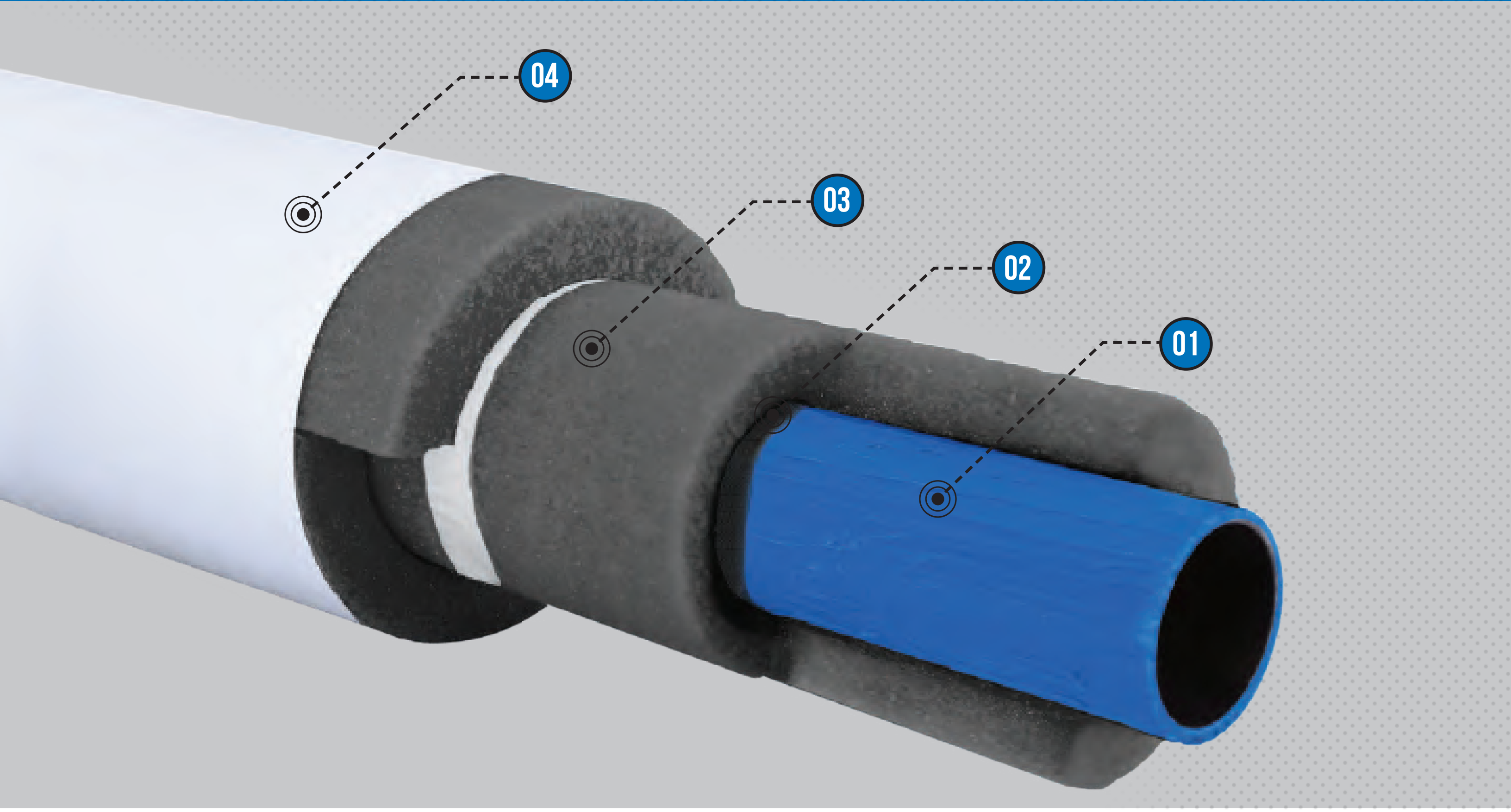
(18) $VC = VE_{DX} + VE_{OF} + FG + V_{BD}$

(19) $VC = VE_{DX} + VE_{OF} + V_{BD} + L_{in} \times \frac{LC}{h_{fg}}$

(20) $L_{in} = VE_{OF} + V_{dsh} + L_{in} \times \frac{LC}{h_{fg}} + L_{out}$

(21) $L_{in} = \frac{VE_{OF} + V_{dsh} + L_{out}}{1 - \left(\frac{LC}{h_{fg}}\right)}$

THE OPTIMAL COLD SERVICE SYSTEM



01 The optimal Cold Service System starts with RG-2400® gel on the pipe to prevent corrosion.

02 VaporGuard™ for use as a vapor stop on sub-freezing insulation systems.

03 DuPont™ Styrofoam™ insulation provides long-term stable R values.

04 The insulation is covered with Polyguard ZeroPerm® or Insulrap™ vapor retarders to keep the insulation dry. Or complete the system with our Alumaguard® family of flexible weatherproof cladding products.

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GEA North America
+1 717 767 6411
sales.unitedstates@gea.com
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