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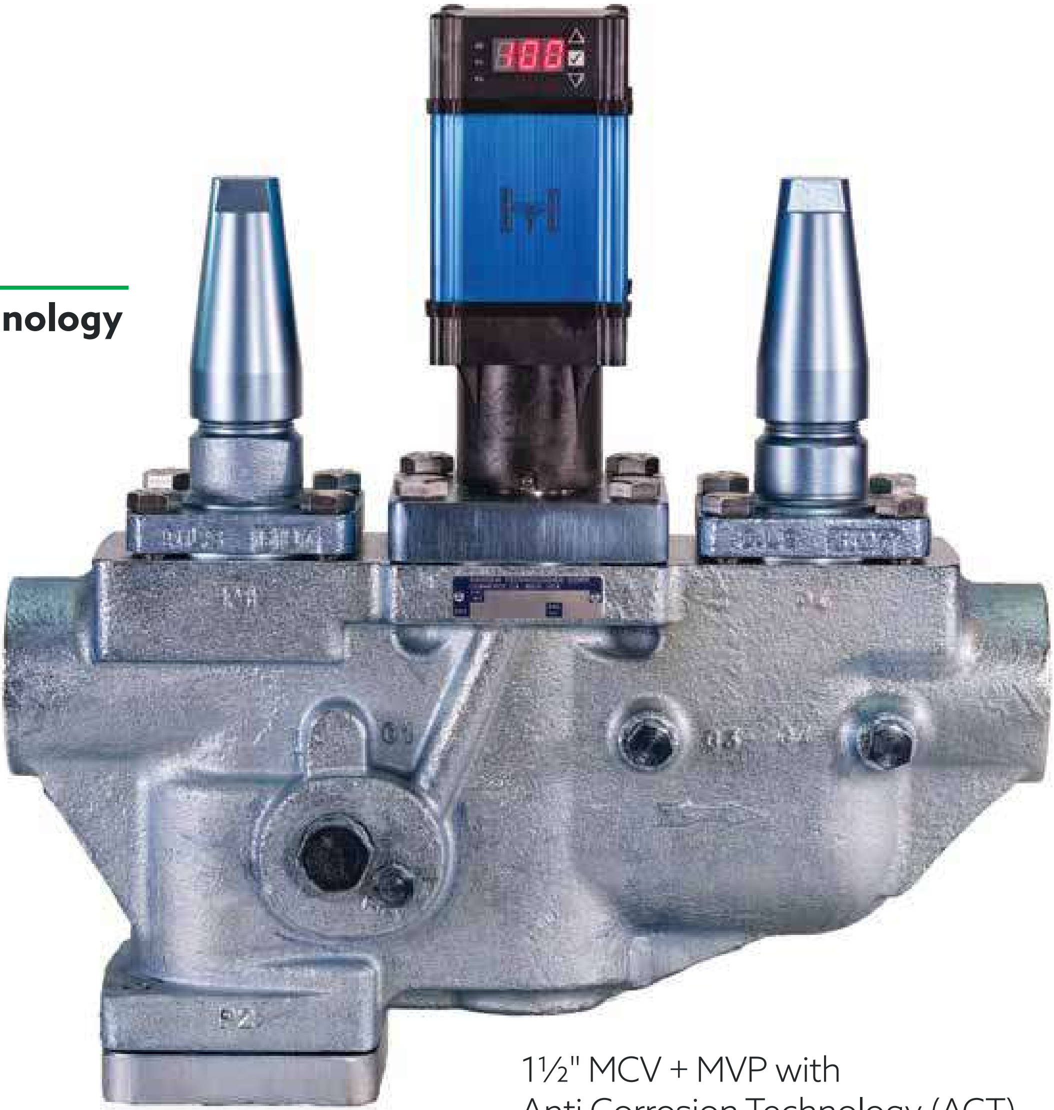
CONDENSER

Reporting RELEASE RATES:

How to find the middle ground



Single Coil Models

Dual Coil Models

AUGUST 2021

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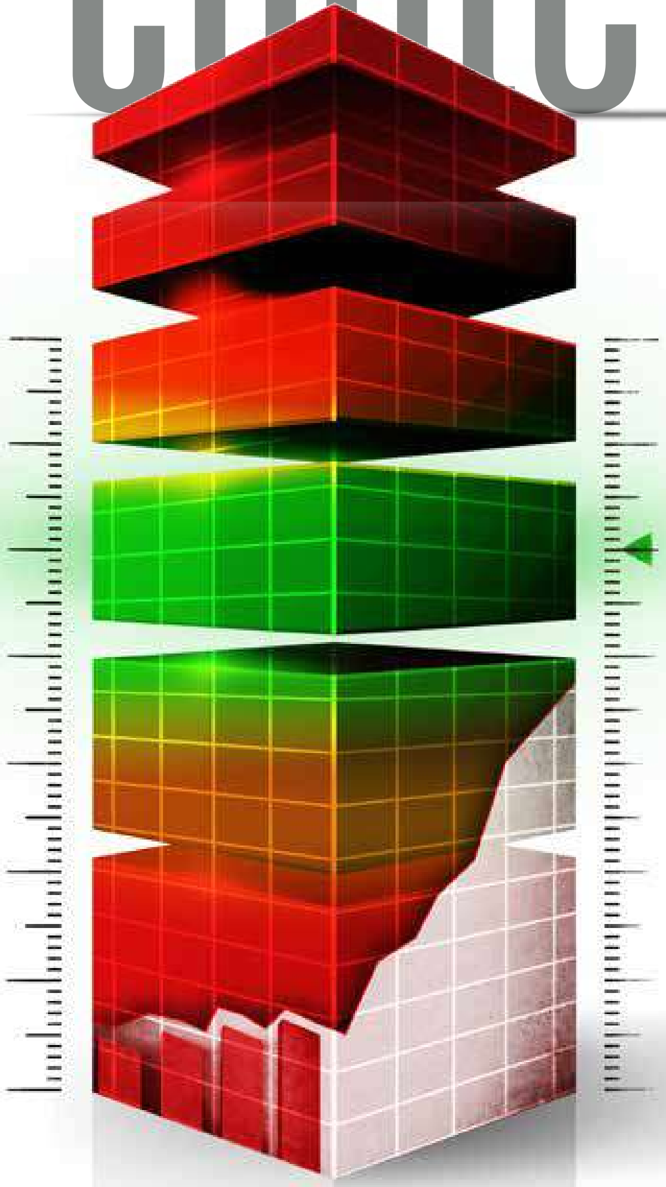

president's MESSAGE

BY GARY SCHRIFT

After a summer of new pandemic news, normalcy has never felt so close and yet so far away at the same time. By the time of this column's publication, your IIAR staff will be busy finalizing a return to in-person IIAR conferences in 2022. We can all look forward now to seeing familiar faces in Savannah, Georgia, next year. And at the same time, the "old normal" will never be the "new normal."

Business models have changed and shifted. Everything from how we work to how we get together to how the pandemic has pushed our technology ahead – sometimes overnight – has yielded a new status quo. These lessons, changes, challenges, and breakthroughs will be with us as we write the next chapter for natural refrigerants.

And sometimes, the change from "old normal" to "new normal" happens so gradually, it's surprising to look back suddenly and see how far we've come. That's the case in our industry, specifically when it comes to codes and standards.

I'd like to take some time in this month's column to recognize an announcement made by Jeff Shapiro, IIAR's Code Consultant, at our recently concluded Natural Refrigeration Conference and Expo.

After years of work, it is more than likely that all code bodies will now refer to IIAR for ammonia refrigeration requirements by 2024. IIAR has made significant progress towards this goal over the past 20 years, but there was one outlier—the International Fire Code. However, the IFC's technical committee has approved a proposal for the 2024 edition of its model code, deferring all matters related to ammonia refrigeration to IIAR (read more on page 12 of this issue).

The inclusion of the International Fire Code in IIAR's long roster of code bodies which refer to IIAR for ammonia refrigeration requirements may seem like an incremental change, but it's the culmination of a decades-long effort. Suddenly, the "new normal" is here.

The inclusion of the International Fire Code in IIAR's long roster of code bodies which refer to IIAR for ammonia refrigeration requirements may seem like an incremental change, but it's the culmination of a decades-long effort. Suddenly, the "new normal" is here.

As of the 2021 model codes, the International Mechanical Code (IMC), ASHRAE-15, the Uniform Mechanical Code (UMC), and the National Fire Protection Association (NFPA), all agreed to defer to IIAR-2 and other IIAR standards as the entire basis of regulating ammonia, Jeff said while speaking during IIAR's annual meeting.

He added that "about a month ago the technical committee for IFC approved a proposal to eliminate the mechanical refrigeration requirements in the IFC for ammonia systems and to defer to IIAR."

"Beginning in 2024, if our IFC [proposal] is successful, the only other document that will regulate ammonia refrigeration safety besides IIAR standards and design is building codes, and building codes apply to all buildings. That isn't unique to ammonia refrigeration."

The IFC change is subject to public comments before final approval. The fire code was the last of the model codes to defer to IIAR for ammonia-related issues.

You can read more about the long history of this effort in this Condenser issue. So I'd like to focus on how significant it is that such a monumental undertaking was completed – all thanks to the sustained hard work and effort of IIAR's dedicated membership. Without the years of work put in by IIAR's code committee, volunteers, members of the board of directors, and especially Jeff Shapiro, we would not be looking forward to a future that will include a much greater degree of influence in our regulatory destiny, than we started with.

As we all look forward to resuming some of our "old normal" activities and traditions, especially our in-person annual conference attendance, I'd like to urge everyone to take a fresh look at IIAR and get involved in defining what's next for all of us.

The best way to do that is to stay informed and find big and little ways to dedicate your time and effort to the cause of natural refrigerants. IIAR runs on volunteer excellence, and there are no shortages of tasks to complete, conversations to have, and new issues to examine.

If you have an interest in any of the activities IIAR is involved in, consider joining a committee, make advance plans to renew your membership, contribute a technical paper or Condenser article, or simply show up with your ideas and enthusiasm. We can't wait to see you in 2022!


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chairman's MESSAGE

BY ERIC JOHNSTON

We're laying the groundwork for 2022's return to an in-person annual conference and setting new agendas these days. And even though I'm well into my term as your IIAR Chairman, I'd like to take this opportunity to welcome everyone – new and renewing members alike.

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

IIAR is embarking on several ambitious goals this year as your staff is busier than ever completing products and projects that move us closer to our strategic vision.

Although the pandemic kept us apart, IIAR's 2020 and 2021 virtual shows have been two of our best conferences yet, and that is always due to the hard work and contributions of IIAR's membership. It's appropriate to take a minute – as we begin our membership renewal effort - and extend special thanks and appreciation to all who contributed their time and financial support to this year's event.

If you didn't already realize that we're in the midst of IIAR membership renewal season, the success of our most recent conferences, even amid difficult circumstances, is a great reminder of how essential IIAR membership is to the leadership of our industry.

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

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

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

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

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

To that end, we'll be focused once more on the work of our committees this year.

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

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

Meet your ammonia safety concerns head-on

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Ammonia in your air is more than just a bad smell.

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Reporting RELEASE RATES:

How to find the middle ground

Estimating the amount of ammonia lost due to an accidental release can be a complex process and when they do occur, end-users want to avoid underpredicting or overpredicting release quantities. Presently, there is not a single reference guideline that provides details for calculating ammonia quantities released as a consequence of incidents. The IIAR Government Affairs Committee identified the need for a single reference guideline and the IIAR Research Committee responded to the need for its development using funding support from the Ammonia Refrigeration Foundation. The result was the preparation of a formal guideline on determining ammonia leak rates for use in estimating accidental release quantities. The guideline is currently undergoing peer review and its release is planned for the fourth quarter this year.

"When covered facilities here in the U.S. have an accidental release of ammonia, they need to quickly determine if the release amount has or will exceed the reportable quantity of 100 pounds," said Douglas Reindl, a professor at the University of Wisconsin and director of the IRC. "If the end-user does not promptly report (they have 15 minutes from when the leak was discovered to make this determination), they are subject to hefty fines."

"Facilities want to accurately report but not over-report to avoid unwarranted regulatory scrutiny, but if you have another situation where there is an accidental release and the neighbors call 911 or the fire department triggering an external response, that will get regulatory attention whether or not the reportable quantity is reached," Reindl said.

Bent Wiencke, who has more than 30 years of experience in the industry, led the Ammonia Refrigeration Foundation-funded research project to prepare comprehensive guidance on estimating ammonia leak rates. He said the research has been challenging due to the complexity of the methodologies, and the guidance document itself quickly exceeded 100 pages in length.

"Some of the equations used for estimating refrigerant release rates are dif-

ficult to solve and detailed explanations had to be provided to remove ambiguity. Furthermore, if we condense this document down to a few pages, regulators could challenge the validity of the document and ask a lot of questions on the method's basis," Wiencke said.

This will be the first formal guideline for estimating accidental release rates specific to the ammonia refrigeration industry. "There are various leak calculators and spreadsheets on leak rates one can find on the internet, but you don't necessarily know where they came from, what they are based on, or their underlying limitations, so some regulators have had issues with facilities using these various leak calculators," Wiencke said. "If you tell me, your total release amount is just below the threshold limit of 100 pounds but you can't tell me how you got to that number, I will assume it is simply based on a guess and not based on any sound and established methodologies."

> "We can actually analyze an entire system of a facility and see in what scenarios a release could occur and estimate how much ammonia would actually be released."
>
> – Bent Wiencke, Ammonia Refrigeration Foundation-funded research project leader

The forthcoming IIAR accidental release calculation guideline will cover single liquid releases with saturated and sub-cooled liquid and gaseous releases with saturated vapor and superheated vapor. The guideline allows users to estimate accidental refrigerant release rates based on some basic inputs that include upstream refrigerant pressure, hole size, and the relevant geometric details that would include the location (where the pipe or vessel wall experiences loss of containment, where a nozzle or valve is sheared off, or a hole is drilled into the vessel or pipe wall, or a pipe section comprising of a pipe section, fittings and valve is severed).

However, it isn't designed to cover severe catastrophic releases that are transient, Wiencke said.

USEFUL RESOURCES

IIAR's release calculation guidance will be a print document, but IIAR is planning to provide an Excel-based spreadsheet that will facilitate solving those complex equations.

"I started realizing very quickly that these equations are very cumbersome to solve, and all of the guideline's users would have to 'program' the equations themselves, which is repetitive and prone to error for each user," Wiencke said, adding that providing a single source spreadsheet will make it easier for people using the tool and allow them to more quickly calculate release rates. "You plug in hole size, pressure and if the liquid is saturated or subcooled or the vapor is saturated or superheated and within a minute, you have an estimate. If you started entirely from scratch, it would probably take several hours to solve some of the more difficult relevant equations."

The guidance can also help with planning. "With ammonia, we do Process Hazard Analysis and these analyses often look at worst-case scenarios involving accidental releases at various locations throughout a system. The spreadsheet will be handy because we can do an analysis of our systems and quickly determine how severe could a worst-case scenario be by performing quick calculations using the Excel spreadsheet template," Wiencke said. "We can actually analyze an entire system of a facility and see in what scenarios a release could occur and estimate how much ammonia would actually be released."

While these formal guidelines on estimating accidental leak rates and the research IIAR is doing on machine room ventilation are standalone projects, there is a connection, Wiencke said. "They are independent, but they are covering some of the same issues we have in the industry," he said. "The machinery room ventilation used simulations based on certain accidental release assumptions and you have to make sure the corresponding release rate calculations are correct. So, I collaborated with the primary researcher on that project to make sure we're internally consistent on our accidental release rates."

FUGITIVE RELEASES

Independent of the ARF project on ammonia release rate determination, the ammonia refrigeration industry has also been examining fugitive emissions of ammonia, the unintended and undetected loss of refrigerant from a refrigeration system that occurs intermittently or continuously, which can be difficult to calculate.

Eric Smith, vice president, and technical director at IIAR said it is important to distinguish between release rates

Fugitive Emissions Resources

Fugitive Emissions Guidance Document:

Best Practices for Reducing Fugitive Emissions from Industrial Refrigeration Systems

Related Webinars:

Pollution Prevention Opportunities for Ammonia Emissions in the Food and Beverage Sector

Best Practices for Reducing Fugitive Emissions From Ammonia Refrigeration Systems Used in the Food and Beverage Sector

Tools:

Dynamic Charge Calculation Tool

Fugitive emissions bagging tool

resulting from fugitive emissions and an accidental uncontrolled release. “What is interesting is that all refrigeration systems seem to have some amount of fugitive emissions, whether that be from service venting or very small leaks from the system,” he said, adding that it is not uncommon for some facilities to lose between 6 and 20 percent of the total refrigerant charge from their system on an annualized basis, but fugitive emissions from ammonia refrigeration systems tend to be lower compared to other refrigerant-based systems because of ammonia’s odor.

> “What is interesting is that all refrigeration systems seem to have some amount of fugitive emissions, whether that be from service venting or very small leaks from the system,”
>
> – Eric Smith, vice president, and technical director at IIAR

“Refrigerated facilities have improved their follow-up based on personnel reporting ammonia odor and refrigeration staff are taking prompt action to identify the leak source and initiating repairs,” Smith said. “Refrigeration systems using fluorochemical refrigerants do not have this same advantage because these refrigerants do not have a distinct odor.”

Reindl said the Industrial Refrigeration Consortium has just finished up a two-year project focused on fugitive emissions from industrial ammonia refrigeration systems, a project funded by EPA Region 5. “One of the goals of the project was to gain a better understanding of the underlying causes for some facilities having to add refrigerant to their systems more frequently and others less frequently.”

During IIAR’s virtual conference, Marc Claas, a research engineer with the Industrial Refrigeration Consortium, discussed results from the fugitive emissions project. “For more than a decade we have informally gathered anecdotal evidence of refrigerated facilities adding between 1 percent of the total system charge annually to more than 100 percent of the total system charge. Data gathered in the field as part of this project is convincing us that the higher end of this range of refrigerant losses for ammonia systems is not attributable to fugitive emissions,” Claas noted.

As part of the fugitive emissions project, the IRC project created a dynamic inventory tracking tool in Excel to help refrigerated facilities more quickly be alerted of potential refrigerant losses due to fugitive emissions. Claas described the inputs to the tool as the high-pressure receiver (HPR) dimensions and orientation, which allows the tool to calculate the vessel’s volume. From there, users begin entering data that includes the date, current HPR liquid level, and the saturation pressure or temperature of the refrigerant in the HPR.

Using refrigerant properties included within the tool, the total charge of refrigerant residing in the high-pressure receiver is calculated. Once a number of data points over a period of time are compiled, the tool plots the HPR charge data to reveal trends in refrigerant inventory.

If the refrigerant loss rate is high, the tool flags facility staff to take action and find the source of refrigerant loss. Claas noted that “at first, the refrigerant inventory data appears a bit random but as users compile more data over a period of time, trends will emerge and the tool can estimate an annual refrigerant loss rate.”

“Ideally you take a charge calculation at some regular interval, daily or weekly, and trend that charge calc over time to see how much refrigerant is leaving the system,” Claas said. “Based on our experience thus far, tracking a single uncontrolled level vessel is enough to trend the overall system charge, with certain caveats considered of course.”

For facilities going several years between “topping off” their system with ammonia, this tracking tool can provide indications of accelerating refrigerant losses and prompt follow-up. The results of the fugitive emissions project show odor screening for ammonia is a good place to start in reducing fugitive emissions. It is also important to investigate potential releases into water or secondary fluids, as these will have low or no odor.

“One problem with fugitive releases is that on an extremely large system, fugitive releases could occur from many small sources on a system,” Smith said.

While a leak from any single point on the system could be much less than 100 pounds per day, combining all the fugitive releases could produce a total exceeding 100 pounds a day, which is a reportable amount. “That is a situation that should be clarified with regulators because the rules are intended to report accidental releases rather than fugitive leaks,” he explained.

Regulatory Requirements for Facilities

In the U.S., facilities are subject to regulatory requirements for notification found in the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Section 103. This regulation requires the person in charge of a vessel containing a hazardous substance as part of a facility to immediately notify the National Response Center whenever a reportable quantity (RQ) or more of a CERCLA hazardous substance is released in any 24-hour period unless the release is federally permitted. The purpose of this requirement is to notify officials of potentially dangerous releases so that they can evaluate the need for a response.

International Fire Code to Defer to IIAR for Ammonia Issues

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"About a month ago the technical committee for IFC approved a proposal to eliminate the mechanical refrigeration requirements in the IFC for ammonia systems and to defer to IIAR," said Jeffrey Shapiro, president of International Code Consultants and a consultant to IIAR. "Beginning in 2024, if our IFC is successful, the only other document that will regulate ammonia refrigeration safety besides IIAR standards and design is building codes, and building codes apply to all buildings. That isn't unique to ammonia refrigeration."

The IFC change is subject to public comments before final approval. The fire code was the last of the model codes to defer to IIAR for ammonia-related issues.

As of the 2021 model codes, the International Mechanical Code (IMC), ASHRAE-15, the Uniform Mechanical Code (UMC), and the National Fire Protection Association (NFPA), all agreed to defer to IIAR-2 and other IIAR standards as the entire basis of regulating ammonia, Shapiro said while speaking during IIAR's annual meeting.

BUILDING ON IIAR'S HISTORY

Eric Smith, Vice President and Technical Director at IIAR, said the progress builds on IIAR's history. "The association was formed originally because there was an emergency code provision proposed through the National Electric Code that would have classified ammonia as a flammable substance that would have to be regulated by Class I Division II electrical equipment," he said, explaining that the shift would have been disastrous for the ammonia refrigeration industry. "IIAR was formed to essentially challenge that proposed regulation."

Ultimately, the NEC technical committee approved a modification that somewhat helped ammonia refrigeration in the 1971 code, but leaders in the ammonia refrigeration industry realized that ammonia needed its own association looking over its interests.

"IIAR was formed in 1971," Shapiro said, adding that it is now celebrating its 50th anniversary. "A lot of people who have come to the industry in the past 10-15 years may know about the tree but don't understand the roots."

In the years that followed, particularly beginning in the early 70s, the model fire and mechanical codes stepped heavily into regulating the refrigeration industry. "The United States is unique among industrialized nations because the national government does not dictate building construction and fire-safety codes," Shapiro explained. "Model codes provide the basis for building and fire-safety regulations in most U.S. communities, and thereby help to standardize regulations."

Because there are multiple associations publishing codes, including the International Code Council, National Fire Protection Association, and International Association of Plumbing and Mechanical Officials, that generate revenue from code sales, training, etc., those organizations compete for adoptions. "As a result, even though we're going for consistency at the national level, we end up with a lot of inconsistency," Shapiro said.

Different regions of the country used different codes, and some states even left it to local jurisdictions to adopt the codes. "Each of these individual code bodies had their own specific requirements for refrigeration systems and even ammonia refrigeration systems, so depending on which area of the country you were working in, you had to follow the code that prevailed in that area, which didn't always agree with what was stated in other codes, so requirements sometimes varied," Smith said.

What's more, codes were a way to influence the competition. "Competing refrigerants used the model codes as leverage to essentially try to increase the cost and complexity and regulatory environment for ammonia-based systems such that A1 refrigerant systems could slip in much more easily," Shapiro said.

Ultimately, the IIAR board of directors decided it would be advantageous for the industry in many ways if people could use a single source for the design, operation, and installation of ammonia systems, Smith said. "They set about a decades-long project to align requirements and then essentially get these various code bodies to simply reference IIAR standards for ammonia refrigeration systems," he explained.

Shapiro said initially IIAR had a difficult time influencing codes, but over the course of the past 20-plus years, the association has successfully navigated all its desired changes into all the model codes. "That got easier in 2000 when the International Code Council was formed," Shapiro said. "The board set a subsequent agenda several years ago of having IIAR manage our regulatory destiny by getting model codes and ASHRAE 15 to defer regulation of ammonia refrigeration to IIAR standards."

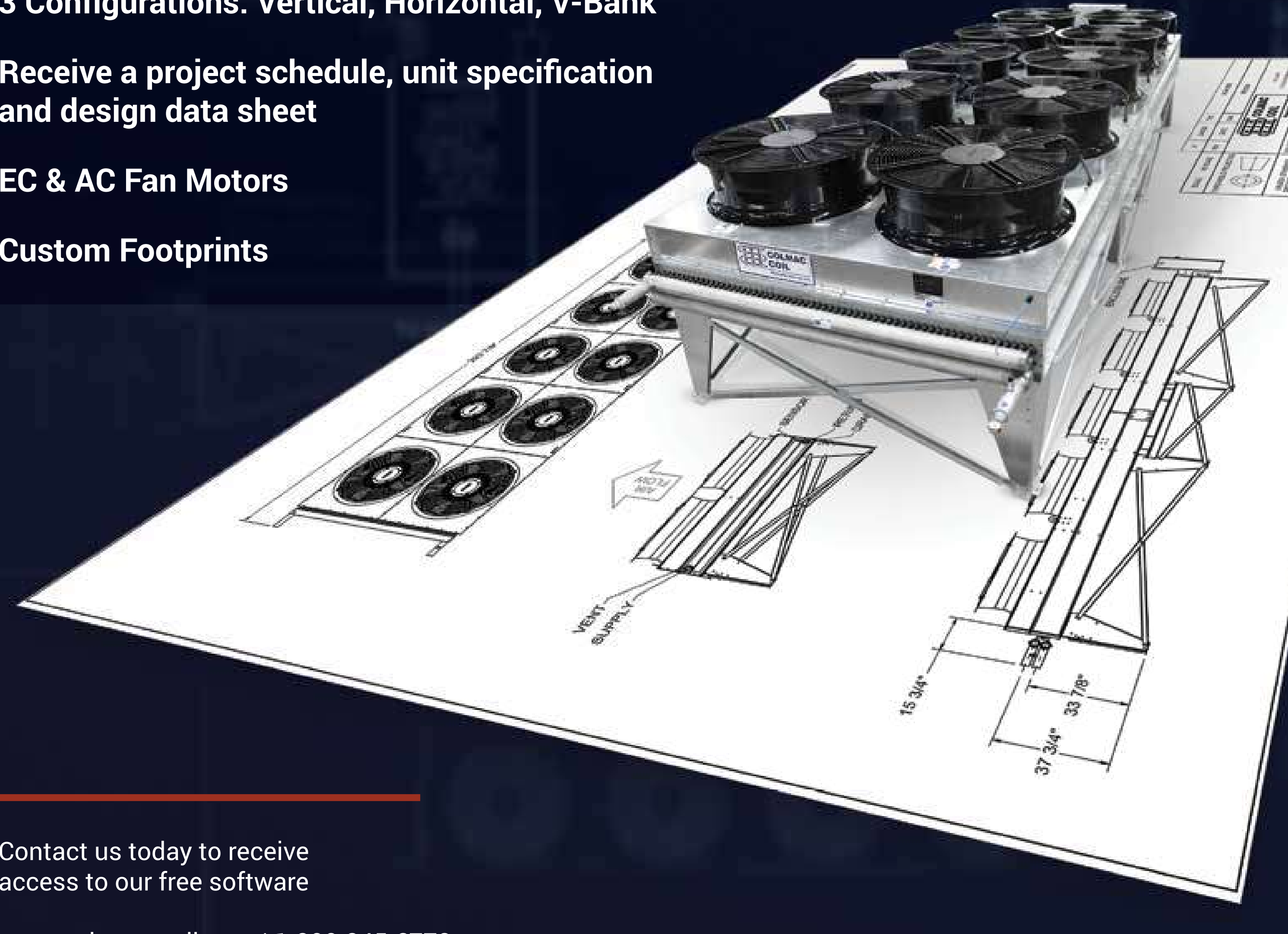
Smith said Shapiro has worked hard to advance IIAR's work. "IIAR really appreciates Jeff's efforts and recognizes his outstanding record in getting this job done for us," he said.

LOOKING AHEAD

The changes will benefit the industry for years to come. In addition, Smith said the having the reference to IIAR 2 for ammonia in ASHRAE 15 has uncomplicated the process for ASHRAE to write their standard to include HFOs.

"Ammonia and HFOs have similar flammability characteristics, but HFOs are heavier than air and have no smell. This means that HFO refrigerant detection is crucial for safe installations, and so ASHRAE has focused on parameters for detector placement and detector response functions without the burden of considering ammonia's unique characteristics. Also, because ammonia is regulated by federal and state government agencies due to its toxicity, it is easier for regulators as well as industry practitioners to be compliant when there is a single source for standards, he said.

However, there is still work to do and those within the industry must remain committed to safety. "Even after all model codes defer to IIAR standards, we are only one major incident away from code officials reconsidering and possibly reversing those deferrals if there is a feeling that IIAR has not been a good steward of building and community safety," Shapiro said. "There is a long history of harsh, kneejerk, reactions to major incidents in model codes. Their attitude is "you didn't fix it, so we're going to fix it for you," so we can't just rest on our laurels and forget where we've come from."


COLMAC
COIL
AIR FLOW
VENT
SUPPLY
15 3/4"
33 7/8"
37 3/4"

Ammonia System Evacuation — How Low Do You Go?

ERIC M. SMITH, P.E., VICE PRESIDENT AND TECHNICAL DIRECTOR,
INTERNATIONAL INSTITUTE OF AMMONIA REFRIGERATION

Removal of non-condensables and excess water is essential when starting up new refrigeration systems or large retrofits. Non-condensables contribute to higher than necessary head pressure, and excessive water in a system can cause inefficiency and operational problems. In all refrigeration systems, non-condensibles and water vapor are removed from systems by vacuum pumps prior to charging with refrigerant. Removing liquid water (dehydration), can be done by "pulling" a deep vacuum – enough to boil the standing water and remove the vapor through the vacuum pump. It is very critical for CO_2 and synthetic refrigerant systems to remove as much water vapor as possible. This will help to prevent the formation of acids and artificially high head pressure. But moisture removal is not as critical in ammonia systems, because ammonia will absorb the water due to its high affinity to it. This means that oil in the system will not be prone to contamination. To be clear, non-condensables should be minimized in any system. So when evacuating ammonia systems, one might wonder how low of a vacuum is low enough, and how much water is too much. IIAR publications regarding evacuation and dehydration have been inconsistent through the years. The following analysis helped the IIAR Standards Committee settle on requirements and recommendations for evacuation and de-hydration which were issued in an interpretation of IIAR 5-2019, *Startup of Ammonia Refrigeration Systems*. Briefly stated, the interpretation says a vacuum of 25"Hg is sufficient if the system is subsequently purged of non-condensables, and there is no reason to believe that excess liquid water is present in a system upon startup. This is a lesser vacuum than was required in IIAR 5-2019. The interpretation request and response can be found on the IIAR website.

Water in a system will be addressed first. A small amount of water in an ammonia refrigeration system is not problematic. Ammonia refrigeration systems will tolerate it with little or no detriment to operation. This is but one great advantage of ammonia over other refrigerants, especially for larger scale systems where opening them for maintenance is common and evacuating them repeatedly would not be possible. Indeed, a trace amount of water in an ammonia system is known to mitigate stress corrosion cracking of carbon steel vessels and piping. It is recommended that ammonia refrigeration systems have at least 0.2% water content for this reason. But excessive water concentrations should also be avoided because it can cause problems with efficiency and sometimes operation. Water that has been absorbed into ammonia can raise the boiling point of the mixture, which could require the suction pressure be unnecessarily low to accommodate a given load, resulting in inefficiency. Additionally if the ammonia becomes too saturated, there could be problems with control valve operation, where "freezing" of the mixture could hinder valves' internal functions. It is beyond the scope of this article to explore the properties of aqueous-ammonia (ammonium hydroxide), but IIAR 6 requires periodic testing of ammonia on some systems and recommends a maximum water content of 5%. IIAR 6 also has an informative appendix that provides further detail on the effects of water in a system, methods to test its concentration, and methods to remove it.

Water can be present in a system for a number of reasons. It could be left over from equipment that was hydrotested, it could be introduced through leaking heat exchangers, it can accidentally be drawn into a system during maintenance procedures that use water to capture ammonia vapor. It can enter a system that is under construction and left open to the weather, and likely other reasons. In all circumstances, excessive water should be kept out of a system during construction, and any hydrotested equipment should be examined for standing water prior to installation. But water can also be present because water vapor in air has either entered a system during operation (especially on systems that operate in a vacuum) or was not removed before a system was charged and started.

If ammonia is tolerant to some amount of water, it is worth considering how low a vacuum is necessary when removing water vapor and non-condensables from an ammonia system. A deeper vacuum will remove more water vapor (and more non-condensable gases). But a lesser vacuum is easier to achieve, and the consequences are not severe in most circumstances. Following are engineering calculations to quantify the effects of vacuum to remove water vapor (non-condensables will be addressed later). A theoretical "large" system is used in this example. It has an ammonia charge of 10,000 lbs and an internal volume of 819 ft3.

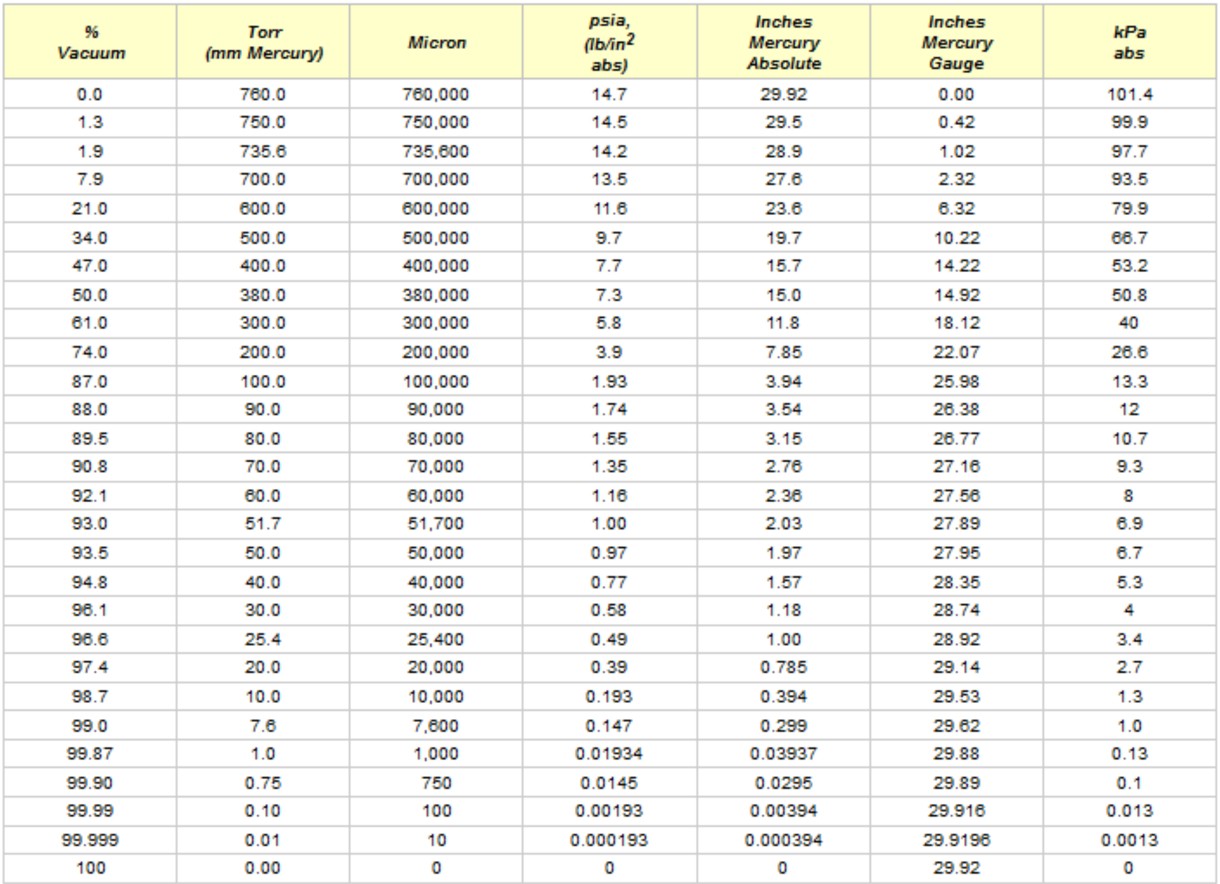
The water vapor within a system will behave like an ideal gas, and thus the use of ideal gas laws and equations are applicable. It may be helpful to review some basic terminology used to describe pressure and vacuum pressure.

Absolute Pressure (P_{abs}) is the pressure relative to the zero pressure in the empty, air free space of the universe. It includes the pressure due to the mass of the atmosphere (P_{atm}, atmospheric pressure) and is used in ideal gas calculations.

Gage pressure (P_g) is the difference between absolute pressure less atmospheric pressure. $P_g = P_{abs} - P_{atm}$. Gage pressure is used most commonly when discussing refrigeration system pressures.

Vacuum pressure is the pressure that exists below atmospheric pressure. A perfect vacuum would mean that the absolute pressure is zero. This is a theoretical condition that can only be approached in practice. As such, there is always some positive value for absolute pressure, whether gage pressure is positive or negative (vacuum condition). There are several common units used to describe vacuum gage pressure. The following table easily depicts these units. Inches of mercury column ("Hg) and microns are most commonly used when discussing refrigeration vacuum pressure.

TABLE 1 – VACUUM PRESSURE VALUES



% Vacuum	Torr (mm Mercury)	Micron	psia, (lb/in^2 abs)	Inches Mercury Absolute	Inches Mercury Gauge	kPa abs
0.0	760.0	760,000	14.7	29.92	0.00	101.4
1.3	750.0	750,000	14.5	29.5	0.42	99.9
1.9	735.6	735,600	14.2	28.9	1.02	97.7
7.9	700.0	700,000	13.5	27.6	2.32	93.5
21.0	600.0	600,000	11.6	23.6	6.32	79.9
34.0	500.0	500,000	9.7	19.7	10.22	66.7
47.0	400.0	400,000	7.7	15.7	14.22	53.2
50.0	380.0	380,000	7.3	15.0	14.92	50.8
61.0	300.0	300,000	5.8	11.8	18.12	40
74.0	200.0	200,000	3.9	7.85	22.07	26.6
87.0	100.0	100,000	1.93	3.94	25.98	13.3
88.0	90.0	90,000	1.74	3.54	26.38	12
89.5	80.0	80,000	1.55	3.15	26.77	10.7
90.8	70.0	70,000	1.35	2.76	27.16	9.3
92.1	60.0	60,000	1.16	2.36	27.56	8
93.0	51.7	51,700	1.00	2.03	27.89	6.9
93.5	50.0	50,000	0.97	1.97	27.95	6.7
94.8	40.0	40,000	0.77	1.57	28.35	5.3
96.1	30.0	30,000	0.58	1.18	28.74	4
96.6	25.4	25,400	0.49	1.00	28.92	3.4
97.4	20.0	20,000	0.39	0.785	29.14	2.7
98.7	10.0	10,000	0.193	0.394	29.53	1.3
99.0	7.6	7,600	0.147	0.299	29.62	1.0
99.87	1.0	1,000	0.01934	0.03937	29.88	0.13
99.90	0.75	750	0.0145	0.0295	29.89	0.1
99.99	0.10	100	0.00193	0.00394	29.916	0.013
99.999	0.01	10	0.000193	0.000394	29.9196	0.0013
100	0.00	0	0	0	29.92	0

Table from “engingeeringtoolbox.com”

Start with the system full of saturated air at 90 deg F, 90% relative humidity (RH) and at atmospheric pressure (14.7 psia) and determine the mass of water vapor in the air before vacuum:

First, determine the pressure of the water vapor:

$$RH = \emptyset = \frac{Pressure\ of\ water\ vapor\ (P_w)}{saturation\ pressure\ of\ water\ at\ 90°\mathrm{F}\ (P_{sat})} = 0.90$$

And from steam tables we can find that:

$$P_{sat\ @90°\mathrm{F}} = 0.6982\,\frac{lbf}{in^2}x144\,\frac{in^2}{ft^2} = 100.5\,\frac{lbf}{ft^2}$$

Therefore: $P_w = 90.487\,\frac{lbf}{ft^2}$

Now, consider the ideal gas equation: $P_w V = mRT$

Where:

$$P_w = Pressure\ of\ water\ vapor = 90.487\,\frac{lbf}{ft^2}$$

$$V = volume\ of\ the\ system = 819ft^3$$

$$m = mass\ of\ water\ vapor = unknown$$

$$T = temperature\ of\ the\ water\ vapor = 90°F + 460 = 550°R$$

$$R = specific\ gas\ constant\ for\ water = 85.8\frac{ft \cdot lbf}{lb \cdot °R}$$

Solving for m:

$$m = \frac{90.487\frac{lbf}{ft^2} \cdot 819ft^3}{550°R \cdot 85.8\frac{ft \cdot lbf}{lbm \cdot °R}} = 1.57\ lbm\ of\ water\ vapor$$

This can also be done by use of psychrometric charts (or similar computers) finding that for 90°F air at 90% RH, there is $14.48\frac{ft^3}{lbm,dry\ air}$ and the humidity ratio $(\omega) = 0.028\frac{lbm,water\ vapor}{lbm,dry\ air}$

And so: $819ft^3 \cdot \frac{lbm,dry\ air}{14.48ft^3} = 56.6\ lbm, dry\ air$

Therefore: $56.6\ lbm, dry\ air \cdot \frac{0.028\ lbm,water\ vapor}{lbm,dry\ air} = 1.58\ lbm\ of\ water\ vapor$, which is *very close* to the calculation above.

One can also calculate the partial pressure of air in the system, and subsequently the mass of air in the system.

$\omega = \frac{R_{air}P_{water}}{R_w P_{air}}$, noting that $R_{air} = 53.3\frac{ft \cdot lbf}{lbm \cdot °R}$

So, using values given previously:

$$\omega = \frac{53.3 \cdot P_w}{85.3 \cdot P_{air}} = 0.621\frac{P_w}{P_{air}}$$

Dalton's law of partial pressure states that the pressure of a mixture is equal to the sum of the pressures of the components of the mixture. Thus the total pressure of the air/water vapor mixture is the sum of the partial pressure of the air plus the partial pressure of the water:

$$P_{mixture} = P_{air} + P_w$$

It is known that: $P_{mixture} = 14.7\ psia, or\ 14.7\frac{lbf}{in^2} \cdot 144\frac{in^2}{ft^2} = 2116.8\frac{lbf}{ft^2}$

Using the value for P_w we calculated above:

$P_{air} = 2116.8\frac{lbf}{ft^2}$ - $90.487\frac{lbf}{ft^2} = 2026.3\frac{lbf}{ft^2}$

$\omega = 0.621\frac{P_w}{P_{air}} = 0.621\frac{90.487}{2026.3} = 0.0277$ and this *very closely* matches the psychrometric chart.

Using the ideal gas equation for air:

$$m = \frac{P_a \cdot V}{R_a \cdot T_a} = \frac{2026.3 \cdot 819}{53.3 \cdot 550} = 56.6\ lbm, dry\ air$$

This can also be calculated with $\omega = \frac{m_w}{m_a} \rightarrow m_a = \frac{1.58}{0.0277} = 57.03\ lbm, dry\ air$

and checked with a psychrometric chart, finding again at 90°F, 90% RH, 14.7$psia$ there is $14.48 \frac{ft^3}{lbm, dry\ air}$.

Using the volume of the system: $\frac{819 ft^3}{14.48 \frac{lbm, dry\ air}{ft^3}} = 56.6\ lbm, dry\ air$

The mass of the water vapor/air mixture can now be determined:

$$m_{mix} = m_a + m_w \rightarrow 56.6 + 1.57 = 58.17\ lbm, mix$$

Now the specific gas constant for the mixture can be determined using the ideal gas equation:

$$R_{mix} = \frac{P_{mix} \cdot V}{m_{mix} \cdot T_{mix}} = \frac{2116.8 \cdot 819}{58.17 \cdot 550} = 54.187\ \frac{ft \cdot lbf}{lbm \cdot °R}$$

Now, consider "pulling the system into a vacuum". Each "gulp" of the vacuum pump is pulling a homogeneous mixture of air and water vapor, and the mixture will be at the same humidity ratio, regardless of the beginning or ending pressure.

If a vacuum level of 25"Hg is attained, how much water remains in the system?

$$25"Hg = 2.423\ psia\ =\ 348 \frac{lbf}{ft^2}$$

The mixture is considered an ideal gas. Using the ideal gas equation at the new pressure, and assuming that the temperature will equalize to the ambient temperature (heat will transfer through the piping to the mixture):

$$m_{mix} = \frac{P_{mix} \cdot V}{R_{mix} \cdot T_{mix}} = \frac{348 \cdot 819}{54.187 \cdot 550} = 9.56\ lbm, mix$$

Remembering that the humidity ratio is the same at vacuum conditions as at the beginning conditions, we can determine how much water remains after the vacuum.

$$\omega = \frac{m_w}{m_a} = \frac{m_{mix} - m_a}{m_a} \rightarrow 0.028 = \frac{9.56 - m_a}{m_a} \rightarrow m_a = 9.26\ lbm, dry\ air$$

And therefore:

$m_w = m_{mix} - m_a \rightarrow 9.56 - 9.25 = 0.26\ lbm, water$ after vacuum.

The concentration of water to ammonia, by volume, can now be determined.

First determine the volume of ammonia:

At 90°F, $the\ density\ (\rho)\ of\ ammonia = 36.94\ \frac{lbm}{ft^3}$

So there will be $10{,}000 \frac{lbm}{36.94 \frac{lbm}{ft^3}} = 270\ ft^3 NH_3$

Now determine the volume of water after vacuum:

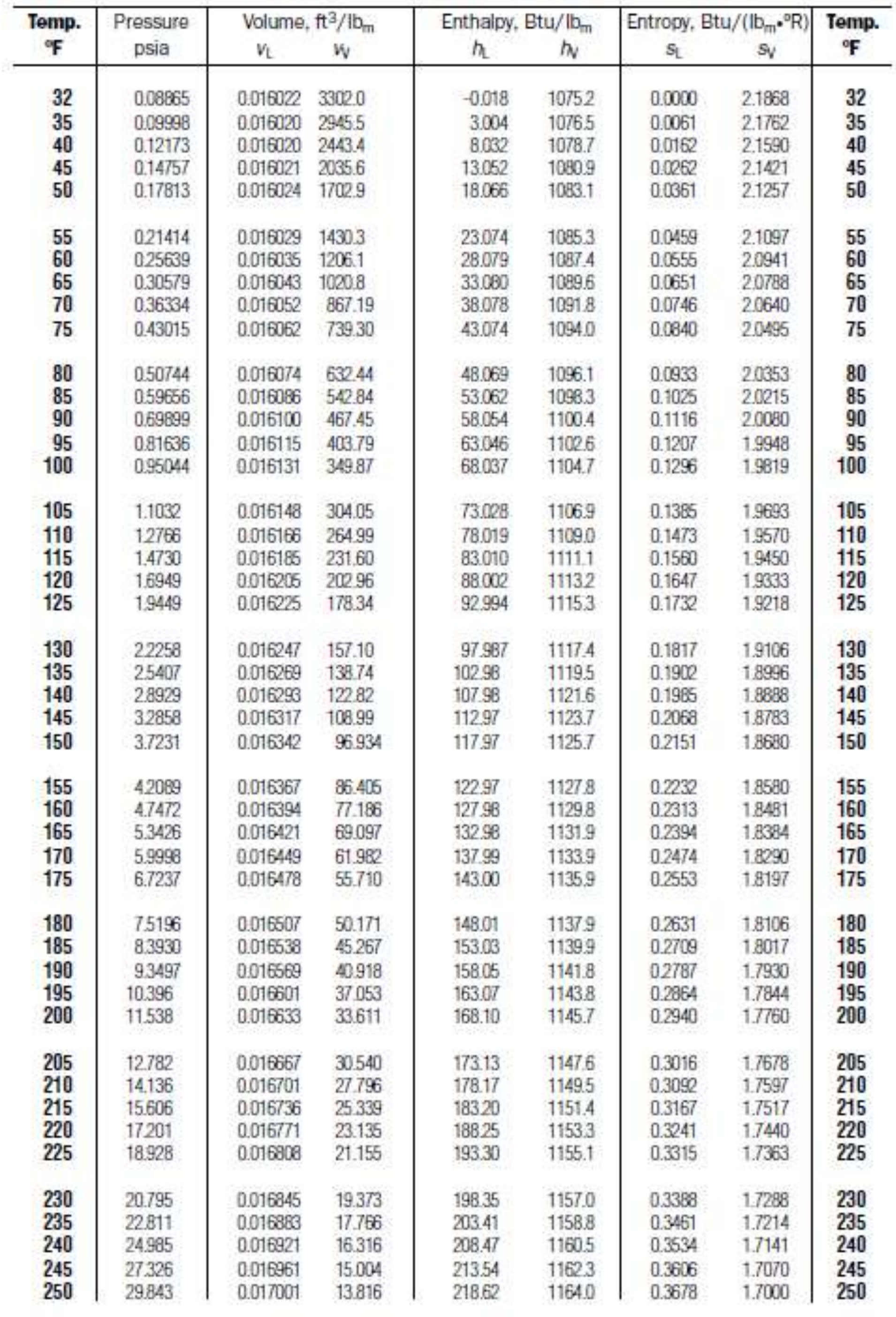
At 90°F, $\text{the specific volume of liquid water } (v_f) = 0.016099\, {}^{ft^3}/_{lbm}$

$$V_w = m_w \cdot v_f \rightarrow 0.26\ lbm \cdot 0.016099 \frac{ft^3}{lbm} = 0.0042\ ft^3$$

A simple ratio gives:

$$\frac{0.0042 ft^3\ water}{270 ft^3 NH_3} = \frac{x\ parts\ water}{1{,}000{,}000\ parts\ NH_3} \rightarrow 15.5\ ppm \frac{water}{NH_3}\ or\ 0.002\%$$

So it can be seen that water vapor remaining in a system after a vacuum to 25”Hg is not a concern. But if there is reason to believe that standing water remains in the system after efforts have been made to remove it during construction and prior to evacuation, water can most often be boiled out by increasing the level of vacuum, thus lowering the boiling point of the water within the system. Of course ambient conditions must be above freezing, and indeed relatively warm for this to be accomplished, as will soon be explained. It is also worth noting that a system that is vacuumed too low, too quickly can cause any standing water to freeze, making dehydration by vacuum extremely difficult. An examination of steam tables helps to demonstrate these concepts. As mentioned earlier, it is recommended that a system have at least a 0.2% water content to help mitigate stress corrosion cracking. It is therefore not generally a good idea to use metallurgic grade ammonia (which is very “dry”) for a system’s initial charge, because, as has been demonstrated, an appropriately evacuated and carefully constructed system will not have much water in it before charging.



Temp. °F	Pressure psia	Volume, ft^3/lb$_m$		Enthalpy, Btu/lb$_m$		Entropy, Btu/(lb$_m$•°R)		Temp. °F
		v_L	v_V	h_L	h_V	s_L	s_V	
32	0.08865	0.016022	3302.0	-0.018	1075.2	0.0000	2.1868	**32**
35	0.09998	0.016020	2945.5	3.004	1076.5	0.0061	2.1762	**35**
40	0.12173	0.016020	2443.4	8.032	1078.7	0.0162	2.1590	**40**
45	0.14757	0.016021	2035.6	13.052	1080.9	0.0262	2.1421	**45**
50	0.17813	0.016024	1702.9	18.066	1083.1	0.0361	2.1257	**50**
55	0.21414	0.016029	1430.3	23.074	1085.3	0.0459	2.1097	**55**
60	0.25639	0.016035	1206.1	28.079	1087.4	0.0555	2.0941	**60**
65	0.30579	0.016043	1020.8	33.080	1089.6	0.0651	2.0788	**65**
70	0.36334	0.016052	867.19	38.078	1091.8	0.0746	2.0640	**70**
75	0.43015	0.016062	739.30	43.074	1094.0	0.0840	2.0495	**75**
80	0.50744	0.016074	632.44	48.069	1096.1	0.0933	2.0353	**80**
85	0.59656	0.016086	542.84	53.062	1098.3	0.1025	2.0215	**85**
90	0.69899	0.016100	467.45	58.054	1100.4	0.1116	2.0080	**90**
95	0.81636	0.016115	403.79	63.046	1102.6	0.1207	1.9948	**95**
100	0.95044	0.016131	349.87	68.037	1104.7	0.1296	1.9819	**100**
105	1.1032	0.016148	304.05	73.028	1106.9	0.1385	1.9693	**105**
110	1.2766	0.016166	264.99	78.019	1109.0	0.1473	1.9570	**110**
115	1.4730	0.016185	231.60	83.010	1111.1	0.1560	1.9450	**115**
120	1.6949	0.016205	202.96	88.002	1113.2	0.1647	1.9333	**120**
125	1.9449	0.016225	178.34	92.994	1115.3	0.1732	1.9218	**125**
130	2.2258	0.016247	157.10	97.987	1117.4	0.1817	1.9106	**130**
135	2.5407	0.016269	138.74	102.98	1119.5	0.1902	1.8996	**135**
140	2.8929	0.016293	122.82	107.98	1121.6	0.1985	1.8888	**140**
145	3.2858	0.016317	108.99	112.97	1123.7	0.2068	1.8783	**145**
150	3.7231	0.016342	96.934	117.97	1125.7	0.2151	1.8680	**150**
155	4.2089	0.016367	86.405	122.97	1127.8	0.2232	1.8580	**155**
160	4.7472	0.016394	77.186	127.98	1129.8	0.2313	1.8481	**160**
165	5.3426	0.016421	69.097	132.98	1131.9	0.2394	1.8384	**165**
170	5.9998	0.016449	61.982	137.99	1133.9	0.2474	1.8290	**170**
175	6.7237	0.016478	55.710	143.00	1135.9	0.2553	1.8197	**175**
180	7.5196	0.016507	50.171	148.01	1137.9	0.2631	1.8106	**180**
185	8.3930	0.016538	45.267	153.03	1139.9	0.2709	1.8017	**185**
190	9.3497	0.016569	40.918	158.05	1141.8	0.2787	1.7930	**190**
195	10.396	0.016601	37.053	163.07	1143.8	0.2864	1.7844	**195**
200	11.538	0.016633	33.611	168.10	1145.7	0.2940	1.7760	**200**
205	12.782	0.016667	30.540	173.13	1147.6	0.3016	1.7678	**205**
210	14.136	0.016701	27.796	178.17	1149.5	0.3092	1.7597	**210**
215	15.606	0.016736	25.339	183.20	1151.4	0.3167	1.7517	**215**
220	17.201	0.016771	23.135	188.25	1153.3	0.3241	1.7440	**220**
225	18.928	0.016808	21.155	193.30	1155.1	0.3315	1.7363	**225**
230	20.795	0.016845	19.373	198.35	1157.0	0.3388	1.7288	**230**
235	22.811	0.016883	17.766	203.41	1158.8	0.3461	1.7214	**235**
240	24.985	0.016921	16.316	208.47	1160.5	0.3534	1.7141	**240**
245	27.326	0.016961	15.004	213.54	1162.3	0.3606	1.7070	**245**
250	29.843	0.017001	13.816	218.62	1164.0	0.3678	1.7000	**250**

Table from ASME Steam Tables, Compact Version.

Assume, for example, the system is put into a 25”Hg vacuum (gage pressure) or 125,000 microns. Referring to the first table of vacuum pressures and interpolating, we see that 25”Hg (gage) is approximately 2.4225 psia. Reading the steam table, and again interpolating, it can be seen that the water will boil at 133°F. This is obviously not practical because ambient conditions will not be this high nearly anywhere on earth. Now assume ambient conditions are 50°F, like on a nice fall or spring day, and that the temperature of the piping, and thus the water inside it, will equalize. To "boil out the water", a pressure of 0.17813 psia will be required. Referring to the vacuum table and interpolating, it is seen that a vacuum of 29.57"Hg (8,904 microns), will be required to turn the liquid water into vapor and be removed by the vacuum pump- a more difficult accomplishment than achieving 25"Hg (125,000 microns). This reinforces that it is best to take care that standing water is not in the system for any reason when it is constructed. CO_2 and synthetic refrigerants must be very dry inside, so a vacuum of 500 microns is typically specified for such systems. This is a greater than 99.9% complete vacuum, and corresponds to 0.009665 psia, well below the saturation pressure of water at 32°F. This means that ambient temperatures must be sufficient to transfer enough heat to the water such that it will not freeze before the water vapor is removed. This also demonstrates how pulling a vacuum too low, too quickly, can freeze standing water and make dehydration efforts futile. It is worth noting that sometimes systems have been externally heated to help drive out water while the system is being evacuated. But as stated, it is best to be sure during construction that there is not standing water in the system. It can also be seen that pulling a vacuum to at least the saturation pressure of the water at the system's (ambient) temperature can be used to indicate if there is water present. If the vacuum pressure "stalls" at some point, or rises after a predetermined level of vacuum has been reached, this indicates that water is "boiling" off (presuming that there are no leaks in the system). And again, we see the advantage of using ammonia as a refrigerant, because as stated, some water in the system is tolerable, and under normal circumstances a deep level of vacuum is not necessary.

With the issues of water vapor and liquid water addressed, removal of non-condensables will next be examined. Non-condesable gas in a system will eventually make its way to the condenser, "blocking" the flow of discharge gas into it. Stated another way, non-condesnables will consume the volume of the condenser designated for condensing the ammonia. This dramatically raises the head pressure, as will be demonstrated. Purging, either manually or automatically, will dispatch non-condensables, but it might be impossible to even start or continue to run a system that has excessive non-condensable gas, which drives the need for evacuation before startup. Also, non-condensable gas will exist mostly in the form of air, which is mostly composed of nitrogen and oxygen. Oxygen in a system can contribute to stress corrosion cracking, so it is important that its presence is minimized, head pressure issues notwithstanding.

To demonstrate the effect of vacuum and presence of non-condensables, an actual system with an ammonia charge of 5000 lbm and a volume of 534 ft^3 is used. As with the examination of water vapor, we start with the system full of air at 90°F, 90% relative humidity, and at 14.7 psia (atmospheric pressure).

Start by considering the system full of air at the conditions stated above.

The humidity ratio of water vapor to dry air is the same as in our first example, because the starting conditions are the same: $\omega = 0.028$

Consider that the system is pulled into a 25"Hg (gage) vacuum, or about 125,000 microns.

Referring to the vacuum table and interpolating, this pressure equates to $2.4237\ psia\ or\ 349.01\ \frac{lbf}{ft^2}$

From the first example, we know the specific gas constant for the mixture (R_{mix}) of water vapor and air at this humidity ratio is $54.187\ \frac{ft \cdot lbf}{lbm \cdot {}^\circ R}$

The mixture (dry air plus water vapor) temperature is again assumed to be ambient temperature and is: $90°\text{F} + 460 = 550°R$

The mass of the mixture at this vacuum pressure is determined by the ideal gas equation:

$$m = \frac{P_m V}{R_m T} = \frac{349.01 \cdot 534}{54.187 \cdot 550} = 6.25\ lbm, mix$$

The mass of air remaining after vacuum can now be determined:

$\omega = \frac{m_w}{m_a} = \frac{m_m - m_a}{m_a} \rightarrow 0.028 = \frac{6.25 - m_a}{m_a} \rightarrow m_a = 6.08\ lbm$ remaining after vacuum.

Knowing the mass of air in the system after vacuum, the pressure it imposes on a charged system can be determined using the ideal gas equation. The condenser volume on this system is 70 ft^3, and it is assumed that the condenser is normally filled 1/3 full of liquid ammonia, leaving 2/3 of the volume holding ammonia vapor and non-condensables. The design condensing temperature is 95°F. The air in the system (non-condensables) will migrate to the condenser. For this calculation, it is assumed that the air temperature will be that of the ammonia.

$$P_a = \frac{m_a R_a T}{V} = \frac{6.08 \cdot 53.3 \cdot 550}{2/3 \cdot 70} = 3824.7\ \frac{lbf}{ft^2}\ in\ absolute\ pressure$$

$$\frac{3824.7}{144} = 26.56\ psia = 11.86\ psig$$

It can be surmised, even if readers disagree somewhat with the assumptions of volume and/or temperature of the ammonia/air mixture, that air, the most common non-condensable will have a significant impact on the system's head pressure. This relates directly to energy consumption because compressors will have to work against this un-necessary addition of pressure. It is therefore necessary to either purge the non-condensables, or if a method of purging (either automatically or manually) is not available, to evacuate the system to a much greater level of vacuum. This analysis also demonstrates the importance of an automatic purger for any system operating below atmospheric pressure, where a bad seal could introduce air into the system and cause un-necessarily high head pressure. When automatic purgers are not installed, owners or owner's representatives might wish to witness purging, or otherwise require some type of documentation that purging has been accomplished. Because ambient conditions, loads, and condenser conditions can easily change, documentation of purging can be difficult. Likely the best way is to record the system head pressure, compressor loading, and ambient conditions just before and just after a manual purge. It is also worth noting that an additional manual purge might be needed after the system has been running for a while, so that non-condensables in far reaches of the system will have a chance to migrate to the condensers.

For additional considerations of vacuum, readers are referred to Marty Timm's paper *Designing Industrial Refrigeration Systems for Full Vacuum – Considerations* presented at the IIAR 2021 conference. The paper discusses some matters of evacuation presented here, but also investigates the topic of vessel design for vacuum pressure.

IIAR Hosts Successful 50th Annual Meeting

IIAR 2021 Natural Refrigeration Online Conference & Virtual Expo brought technical education, industrial trend insights, and information on products and services to natural refrigeration professionals in June. This was the second time IIAR presented its annual meeting online as COVID-19 continued to create potential disruptions and planning challenges.

While the industry is eager to meet face-to-face again, there are benefits to a virtual format. Having this conference available through streaming offers education for those who can't normally attend," said Gary Schrift, IIAR president, while welcoming virtual attendees.

Attendees come from all facets of the industry including design engineers, contractors, end-users, academics, scientists, trainers, and government agencies.

HONORING IIAR MEMBERS

During the session, Dave Schaefer, IIAR's 2020-2021 chairman and chief engineer at Bassett Mechanical, presented the IIAR Member of the Year Award to Bruce Nelson. The honor is given to an individual to recognize service to the organization that is exceptional and above expectation. As immediate past chair of IIAR, Nelson's ideas and leadership helped guide the IIAR organization through the Covid-19 pandemic. He also led the selection process for recruiting and hiring the new president of IIAR, Gary Schrift.

"Bruce has traveled the world advocating for IIAR, presented many times at IIAR conferences, and was instrumental in helping develop IIAR's new piping handbook, among other important contributions," Schaefer said.

Nelson devoted 40 years of his career to Colmac Coil Manufacturing, retiring on July 4. He is continuing to work in the industry through his newly formed consulting company, Bruce V. Nelson Engineering LLC.

IIAR occasionally elects individuals as honorary life members in recognition of their enduring contributions to the industry. The award grants all the privileges of an IIAR membership at no cost to the recipient. This year the association chose three honorary life members: Rich Merrill, Peter Jordan, and Nelson.

Schaefer said Merrill has generously volunteered his time for years, sharing his extensive code experience with the Standards Committee and chairing the IIAR 1 Standard Committee for many years.

Jordan has also been very involved in the Standards Committee for many years, chaired the IIAR-7 and IIAR-8 Committees, has served on almost every committee, and was IIAR's chairman. "His extensive knowledge of refrigeration and the safety standards have truly improved our standards and made our industry safer," Schaefer said.

IIAR LEADERSHIP

Eric Johnston, IIAR chair-elect, Nominating Committee Chair, and Strategic Planning Committee Chair, announced nominations for new members of the IIAR board of directors. They are Carl Burris of Tyson Foods, Jeff Sutton of Mr. Ammonia Refrigeration, Mark Bazis, Jr. of Refrigeration Consultants Inc., Jim Adler of Hixson, Engineer, Todd Jekel of the University of Wisconsin, and Maxime Girot or Clauger De Mexico.

Members of the board of directors serving second terms are Alexander Vergara of Anheuser-Busch and Wayne Wehber of Vilter. Jeff Carter of General Mills has moved to the Executive Committee.

Board members completing service include Stefan Jensen, Jeremy Klysen, Bob Czarnecki, and Nelson.

IIAR EDUCATION AND RESEARCH

IIAR has become a premier educational association. It has expanded its recent offerings and has more on the way. While speaking during the general session, Nelson reminded members of scholarships that The Ammonia Refrigeration Foundation has available. "We are currently funding eight scholars, including the first international recipient who is from Africa," he said. "Please let your family and co-workers with engineering students know about our ARF scholarship," he said, adding that ARF funds curriculum and course content for the Academy of Natural Refrigerants.

The Ammonia Refrigeration Foundation has three new research projects this year.

IIAR'S FINANCIAL STANDING

The COVID-19 pandemic and the related cancellations of in-person meetings affected IIAR's budget. Dave Malinauskas, 2020-2021 IIAR treasurer and president at Cimco Refrigeration, said 2020-2021 was a challenging year, but decreases in revenue were offset by strong expense management at IIAR.

Payne said the same was true for the foundation. "I am pleased to report that despite the pandemic and the cancellation of planned networking events, the foundation flourishes. The foundation is fiscally solid and performing all of its intended industry-related goals. Your donations have made this possible," he said.

THE FUTURE

As IIAR and its members prepare for the future, Schaefer said the association is focusing on educational content as well as top industry issues. "We continue to make changes that will make our organization stronger going forward," he said.

IIAR Petitions EPA for Increased Hydrofluorocarbon Restrictions

The International Institute of Ammonia Refrigeration and its industry partners have petitioned the Environmental Protection Agency to use its authority under the American Innovation and Manufacturing Act to restrict the use of hydrofluorocarbons within the refrigeration sector. The AIM Act is a new climate law passed in December 2020.

The rule proposes an allowance allocation and trading system, which will determine the amount of HFCs an entity can produce or consume, and it creates the mechanism to phasedown domestic HFCs.

The agency's first proposed rulemaking under the AIM Act would set the HFC production and consumption baseline levels from which reductions will be made, establish an initial methodology for allocating HFC allowances for 2022 and 2023, and create a robust, agile, and innovative compliance and enforcement system, the agency said.

IIAR's petition, which was sent to EPA Administrator Michael Regan, calls for the EPA to limit the use of refrigerants of 150 or greater GWP in the refrigeration sector in general (both commercial and industrial). The petition identifies several areas, including food retail, cold storage warehouses, and manufacturing, where these limits could be set in place.

In the petition, Gary Schrift, IIAR's president, said the association believes that California's framework for HFC phase-down can serve as a good model for EPA's implementation of the AIM Act. However, IIAR petitions to go further regarding Chillers for Industrial Refrigeration. "Subsection (i) of the AIM Act on 'Technology Transitions' authorizes EPA to 'restrict, fully, partially or on a graduated schedule, the use of a regulated substance in the sector or subsector in which the regulated substance is used,'" according to the petition.

IIAR wrote that the technology has existed for decades in the design and manufacturing of chillers for industrial process refrigeration using natural refrigerants for all temperature ranges. "The use of natural refrigerants including CO_2, ammonia, and hydrocarbons will significantly and positively impact global warming reduction goals using refrigerants with ultra-low refrigerant GWP values and increased operational energy efficiency of these refrigeration systems," IIAR wrote in the petition.

This partial restriction would apply to refrigerants used in "new" equipment, which includes a replacement of an existing refrigeration system as defined in the CARB Proposed Regulation Order under the definitions for "New Chiller "and "New Refrigeration Equipment".

The association recommended the chillers for industrial process refrigeration restriction take effect on Jan. 1, 2026, to provide manufacturers, contractors, and owners the time to meet the needs created by this excellent single-step approach.

IIAR is joined by co-petitioners, the Refrigerating Engineers and Technicians Association, and the Ammonia Safety & Training Institute.

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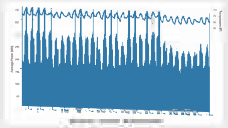
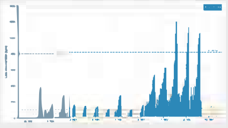


Energy Management



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Is the Era of Ammonia Liquid Overfeed Ending?

STEFAN JENSEN

In four years, it will be the centenary of the liquid overfeed patent issued to YORK Corporation. The liquid overfeed plant came into widespread use around the middle of the last century. This coincided with an upsurge in the consumption of frozen foods that led to the construction of very large freezing plants that warranted the practical introduction of the liquid overfeed concept.

During the 1950s and 1960s, energy efficiency and sustainability were not exactly hot topics. In developed countries, the emphasis then was on converting economies from being agriculturally based towards becoming industrialized and the lifting of middle-class living standards.

The refrigeration industry greats conducted extensive research within the field of ammonia refrigeration. Current industry handbooks still refer to academic research papers authored in the 1950s to the 1980s and these handbooks remain in widespread use within the ammonia refrigeration industry today.

Large ammonia inventories have been under increasing pressure almost throughout the entire world for the last two decades or so. There are various reasons for this, and these mostly relate to the regulatory environments of the individual jurisdictions.

Part of the industry response both in the United States but also in Europe has been the introduction of lower ammonia overfeed rates. Does this prevent elevated pressure drops in the suction line networks of liquid overfeed systems? Mathematically, it does. Commonly used correlations for two phase pressure drops indicate this is the case.

If a plant is designed for an average overfeed rate of 1.5 to 1 at full load, what happens when that plant operates at 20% load? Unless the overfeed ratios of individual evaporators are kept constant irrespective of load, then the average overfeed rate at 20% load will become 7.5 to 1.

> Current industry handbooks still refer to academic research papers authored in the 1950s to the 1980s and these handbooks remain in widespread use within the ammonia refrigeration industry today.

This means that to realize any real energy performance benefits of low overfeed rates for a refrigerating plant, it becomes necessary to apply almost identical control efforts for individual evaporators as one would apply in a dry expansion system.

Refrigerant injection into evaporators of dry expansion NH3 plant is frequently controlled by motorized expansion valves employing the refrigerant wetness (quality) at the evaporator exit as a control signal. How often is this a design feature of practical low overfeed rate installations? Not very often at all – the costs are clearly a deterrent.

What happens if the refrigerant mass flow through an overfeed evaporator is regulated as a function of load? This is not a simple question. To answer that it is necessary to first understand what operating envelope the evaporator in question was designed for at the outset.

In practical liquid overfeed plant design, determination of the optimal evaporator operating envelope is rarely considered in depth. This is because getting it a little wrong does not appear to cause any great problems during commissioning and indeed during operation. It gets cold.

Getting the optimization of the evaporator operating envelope wrong with a dry expansion evaporator can, however, cause significant evaporator performance deficiencies and other issues affecting plant components both upstream and downstream of the evaporator.

Within the context described above, low overfeed evaporators are not that different to dry expansion evaporators. The question is whether this is considered adequately during the design of a low overfeed plant. Are evaporator suppliers provided with the range of conditions that the evaporator will be subjected to throughout its working life or are suppliers being provided with one operating point for the selection/design?

In the last decade, there has been mounting evidence that the liquid overfeed concept prevents ammonia from being the best it can be in terms of energy efficiency. Some of this evidence is illustrated in Figure 1, which shows examples of specific energy consumption values in $kWh \cdot m^{-3} \cdot year^{-1}$ for mixed refrigerated warehouses as a function of refrigerated volume in m^3.

Here it is important to note the relatively close cluster formed by the green dots as opposed to the significant spread between all the remaining dots. The refrigerating plants represented by the green dots all have one thing in common – there is no high-density, liquefied refrigerant present in the suction line network.

All other plants visualized are of the liquid overfeed type. Indeed, the plants represented by the yellow dots were all constructed between 1999 and 2013 for one major logistics operator in Australia, all included the latest energy efficiency measures of that era, and all have been subjected to extensive fine-tuning by the plant owner.

Other evidence is visualized in Figure 2. This illustrates two conceptually identical dual stage, central NH3 refrigerating plants both belonging to the same owner, both situated in the same geographic area, both managed by the same personnel, and both performing identical functions. Both plants employ reciprocating compressors and variable frequency drives throughout.

The smaller plant was constructed in 2010. The larger plant was constructed in 2018 to replace the older plant that had been outgrown by the transport company in question.

The only differences are that one plant is dry expansion (DX) and the other employs liquid overfeed, the DX plant evaporators are specifically designed for that purpose and the DX

Figure 1. Typical Specific Energy Consumption values for refrigerated warehouses.

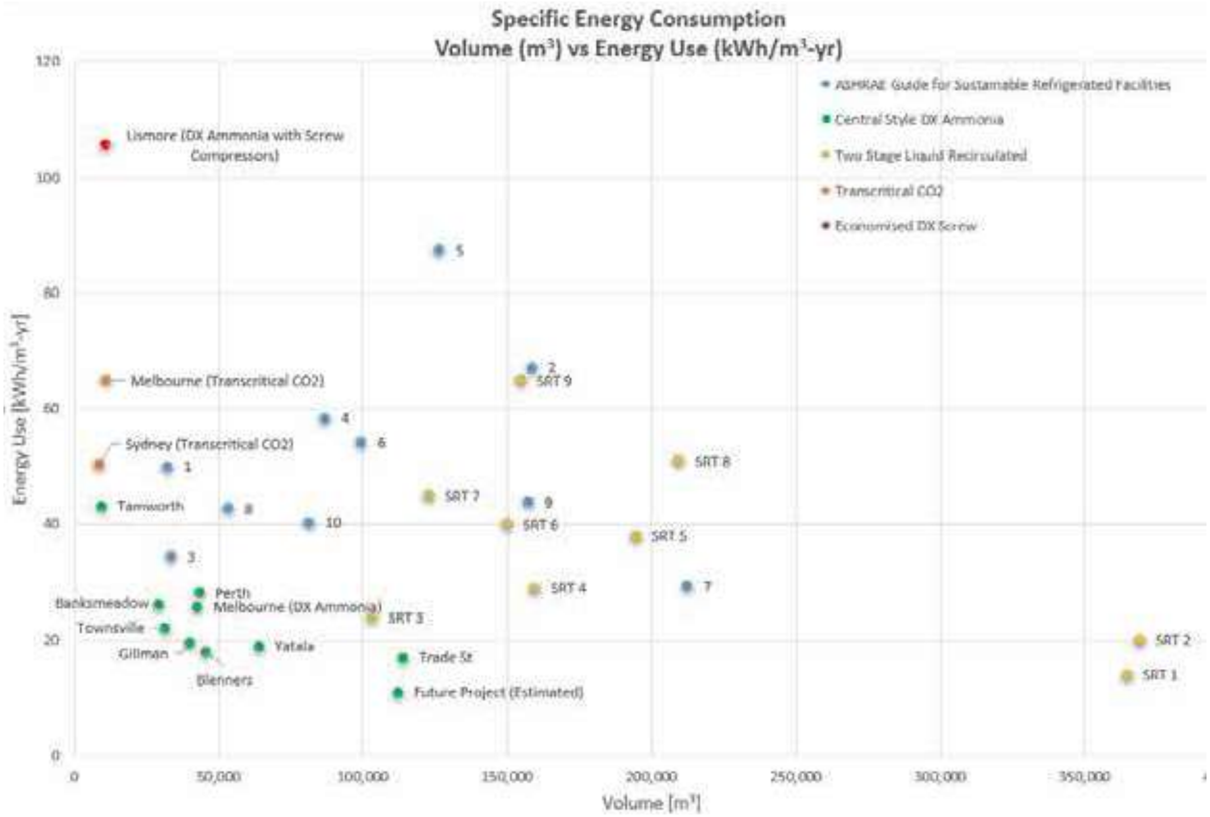


Figure 2. Comparison of Specific Energy Consumption for Liquid Overfeed versus Dry Expansion.

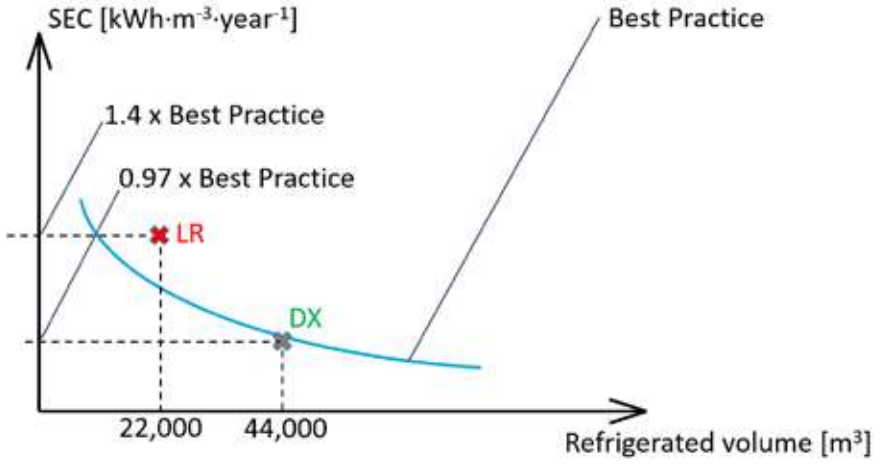
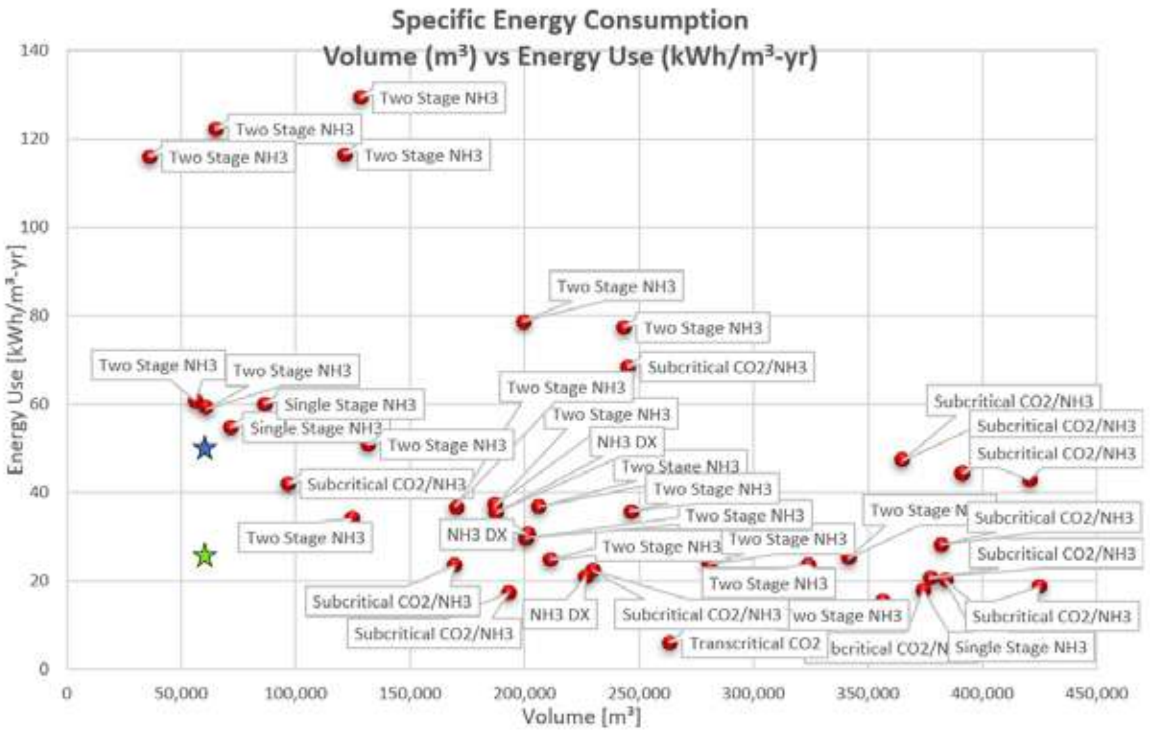


Figure 3. Energy Performance Comparison for 2,100,000 ft^3 DX warehouse with Conventional Plant.



plant condenser is marginally more oversized than the condenser of the liquid overfeed plant. The energy performance records in both cases cover minimum one year – for the older plant several years.

The "best practice" in this context is a polynomial regression analysis of the recorded SEC-values for a range of centralized, low charge NH3 refrigerating plant servicing mixed refrigerated warehouses across Australia. The best practice graph enables the comparison of SEC values for dissimilar refrigerated volumes.

The recorded energy performance penalty associated with the presence of high density, liquefied refrigerant in the suction network is in this practical example around $(1-0.97/1.4)*100 \approx 31\%$. Put another way, the liquid overfeed plant consumes $1.4/0.97=1.44$ times more energy per unit refrigerated volume.

This difference is not explained in full by the minor conceptual differences between the two refrigerating plants. Rather, it is likely that the bulk of the energy performance difference is caused by the differences in refrigerant feed methods.

At the 2017 GCCA Expo in Chicago, the presentation "Low Charge ADX Ammonia" by Watters and Nelson highlighted similar energy performance improvements for centralized, DX NH3 refrigerating plant versus liquid overfeed. The improvement range presented was 18% to 38%, but there were conceptual differences in the practical plant comparisons made to enable postulation of this range.

Figure 3 compares the energy performance of a new 2,100,000 ft^3 mixed warehouse with the energy performances of many North American warehouses employing the plant concepts as marked (red dots). The warehouse represented by the stars is serviced by a dual stage NH3 DX plant that also provides refrigeration capacity to blast freeze 300 metric tonnes of meat in cartons per week.

Again, a similar pattern is visible. Elimination of the liquefied refrigerant from the suction line network appears to deliver significant energy performance benefits.

The blue star represents actual electricity consumption records for the first four months of 2021. These are the warmer months in Australia. The green star represents storage only without blast freezing. This is a calculated correction based on the amount of product frozen.

Does this mean the end of an era for the liquid recirculation concept? To answer this question, it is important to quantify the energy performance penalty associated with mixing relatively high density liquefied refrigerant into the suction network of a large, expansive centralized ammonia refrigerating plant.

Based on the practical observation illustrated in Figure 2, it is postulated here that the energy performance penalty caused by liquid overfeed can be as high as 30%.

The facilities that the comparison in Figure 2 is based on are single-story buildings with ceiling suspended induced draught coolers and valve stations and NH3 pipelines in the ceiling space. At each evaporator outlet is, therefore, a wet riser. Although this may not be ideal for liquid overfeed, it represents a very, very common design.

There is little doubt that had these wet risers been avoidable, the energy performance penalty recorded could have been less or perhaps even nonexistent. However, as most practitioners would know, this is not how things are in practice where the wishes and desires of other project stakeholders often override those of the refrigeration plant designer.

In 2019, an attempt was made by Nitschke to quantify the energy performance penalty of liquid overfeed compared with dry expansion through mathematical modeling. The model used employed the latest Yashar correlation for wet riser pressure drop estimates. This correlation is also a feature of the new IIAR Piping Handbook.

As Nitschke showed in his 2019 Ohrid paper, the modeling failed to provide accurate results below system load percentages of 40% for the plant in question. The Yashar correlation and probably all other such correlations are not valid for the flow reversal scenario in wet risers. This is probably one of the reasons for the spread in liquid overfeed SEC-values in Figure 1.

Plant oversizing is rampant throughout the refrigeration industry. This is not always the fault of designers. Often this is a response to the design brief supplied by plant owners who attempt to plan for future growth. The result, however, is often that plants spend most of their operating lives in part load and wet risers therefore rarely emerge from the flow reversal scenarios.

The symptoms of these things as far as liquid overfeed plants are concerned are well known by most practitioners – liquid management problems, brining, excessive energy consumption, pump cavitation, and excessive ammonia inventories to name a few.

Consider a person standing on a chair with a half-inch garden hose in the mouth and the other end of the garden hose just above the ground. It is very easy breathing through the hose. With the end of the hose in a bucket of water, breathing becomes impossible. The density ratio of air and water is almost identical to the liquid/vapor density ratio of ammonia at -31F, yet these are the working conditions that millions of ammonia boosters are asked to accommodate daily across the world.

Suction line networks of large, expansive liquid overfeed plants can be exceedingly complex. These can connect dozens – at times hundreds of evaporators through pipelines, elbows, tee's, isolation valves, regulating valves, orifices, risers, traps, and droppers. Combine this suction network with evaporators designed to reflect a wide array of rules of thumb relating to bottom feed, top feed, vertical headers, horizontal headers, counter flow, parallel flow, circuit orifices, and the territory quickly becomes one characterized by more unknown unknowns than known unknowns.

By continuing the employment of liquid overfeed as a concept, ammonia refrigerant is prevented from delivering the best energy performance that it is capable of. The answer to the question posed by the title of this article is therefore in the affirmative. The long era of liquid overfeed is ending. It must ensure that ammonia refrigeration is the best it can be and is able to compete in terms of energy efficiency with other natural refrigerant-based solutions.

The technologies required for eliminating liquefied refrigerant from suction lines are available. Unless the ammonia refrigeration industry embraces these technologies, it will miss out on a significant proportion of the refrigerant conversion business that will be a direct result of the global HFC phase-down and – in time – the global HFO phase-down.

REFERENCES:

Watters, R.; Nelson, B.I. "Low Charge ADX Ammonia", Proceedings Global Cold Chain Expo, June 13-15, 2017, Chicago, IL.

Nitschke, T.; Jensen, S.S. "Thermodynamic Modelling of Liquid Overfeed and Dry Expansion Feed Central NH3 Refrigeration Plants to Determine Differences in Energy Performance", Proceedings 8th IIF/IIR Conference Ammonia and CO_2 Refrigeration Technologies, Ohrid, North Macedonia 2019.

Revocable Living Trust

FINANCIAL TECH TIP

SUMMARY:

A revocable living trust can be a useful and practical estate planning tool for certain individuals, but not for everyone. This type of trust is most commonly used to avoid probate because, unlike property that passes by will, trust assets are distributed directly to heirs. This type of trust is also used as a way to maintain management of one's financial affairs during a period of incapacity because someone else can immediately take charge when needed. A revocable living trust does not minimize income, gift, or estate taxes, nor does it shelter trust assets from creditors in most cases.

WHAT IS A REVOCABLE LIVING TRUST?

A revocable living trust (also known as an inter vivos trust) is a separate legal entity created to own property, such as a home or investments.

The trust is revocable, which means that during the grantor's lifetime (the grantor is the person who originally owns the property and creates the trust), he or she controls the trust. Whenever the grantor wishes, he or she can change the trust terms, transfer property in and out of the trust, or end the trust altogether. The trust is called a living trust because it's meant to function while the grantor is alive. The trust can continue after the grantor's death, but the trust becomes irrevocable the moment the grantor dies.

Revocable living trusts are used to accomplish various purposes:

- To ensure that property continues to be properly managed in the event the grantor becomes incapacitated
- To reduce costs and time delays by avoiding probate
- To lessen potential challenges to or elections against a will
- To maintain privacy
- To avoid ancillary administration of out-of-state assets

HOW DOES A LIVING TRUST WORK?

Establishing the trust

Typically, an individual creates and funds the trust, and names himself or herself as both the trustee and sole beneficiary for his or her lifetime (if married, both spouses are typically named beneficiaries). The grantor also names a successor trustee or co-trustee, as well as the beneficiaries who will receive any assets that remain in the trust at the grantor's death. Often, a spouse or child is named as the successor or co-trustee and is also named as an ultimate beneficiary.

Caution: In some states, a co-trustee is required.The grantor continues to manage trust assets during his or her life. Any income earned or expenses incurred by the trust flow through to the grantor on the grantor's individual income tax return. A separate return for the trust is not necessary. In the event the grantor becomes incapacitated (e.g., from illness or injury), the successor trustee or co-trustee can immediately step in to take over the management of the trust on the grantor's behalf, avoiding the need for the grantor's spouse or other family members to petition the court to appoint a guardian. At the grantor's death, assets remaining in the trust pass directly to the beneficiaries, bypassing the probate process. This can save time and money and can minimize some of the burdens of settling the grantor's estate. Tip: If special knowledge or skill is required to manage property in the trust, the successor or co-trustee should be qualified.

Funding the trust

To ensure that the trust fulfills its objectives, the trust must be funded after it is created. Funding the trust means transferring legal title from the grantor into the name of the trust. This may entail recording a new deed for real estate; retitling cars and trucks; renaming checking, savings, and investment portfolio accounts; transferring life insurance policies, stocks, and bonds; executing new beneficiary designation forms; or executing assignments.

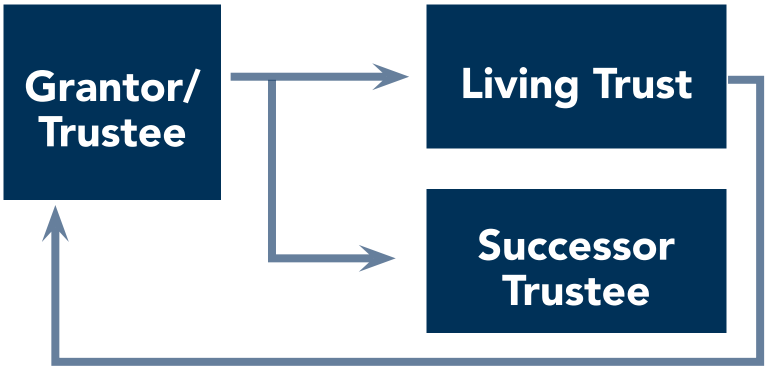
Although a revocable living trust can be funded with virtually any kind of property, including personal property, special consideration should be made before transferring certain types of property, including:

- Incentive stock options
- Section 1244 stock
- Professional corporations

Tip: Transfers to the trust are not considered gifts, so the grantor doesn't need to file a gift tax return.

Living Trust: During Life Illustration

1 Grantor creates trust, names successor or co-trustee, and transfers assets to trust



2 Trust owns transferred assets-distributed income and assets according to trust agreement. Grantor remains responsible for taxes.

3 Successor or co-trustee steps in to manage trust assets if grantor becomes incapacitated, but can't amend or end the trust.

Caution: Some states will reassess the value of a home for property tax purposes when it is transferred to a trust. Some states will disallow income tax deductions related to the home if it is owned by a trust.

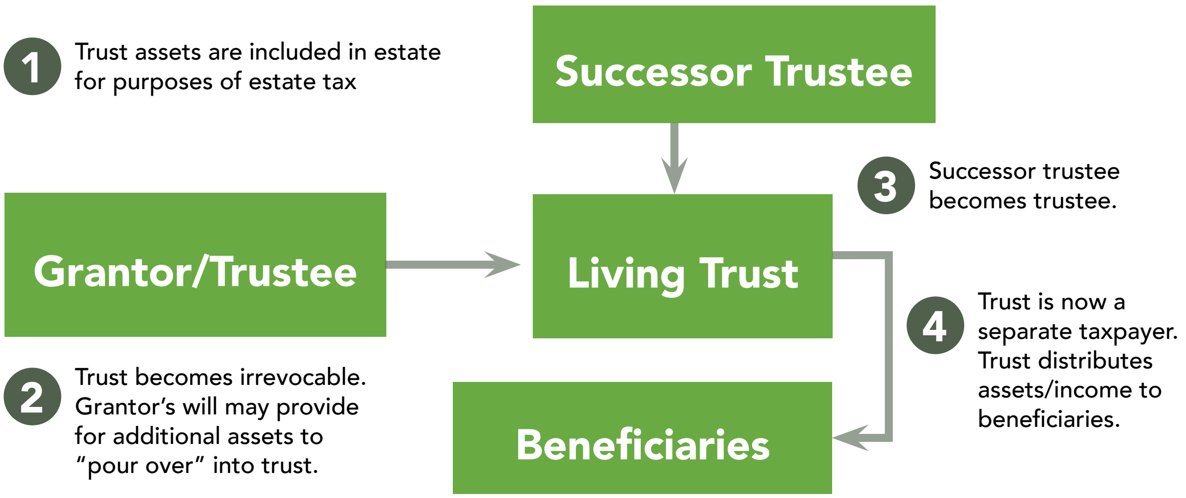
Caution: Some banks may impose a penalty when certificates of deposits (CDs) are transferred to a trust because they consider such transfers to be early withdrawals.

ADVANTAGES

Avoids guardianship

Typically, the grantor names himself or herself as the trustee and someone the grantor trusts or a professional trustee is named as co-trustee or successor trustee. So, if the grantor should become unable to manage the trust assets for whatever reason, the co-trustee or successor trustee can immediately take over control and continue managing the assets with little or no lapse in between. This can be very important with certain types of assets that require frequent attention to maintain their value, such as rental property or a securities portfolio.

Living Trust: At Death Illustration



Avoids probate

The grantor and the grantor's spouse are typically named as the sole beneficiaries of the trust during their lives, and at their deaths, any assets remaining in the trust pass to the grantor's named beneficiaries, usually children and grandchildren. If the grantor can and does transfer all of his or her assets in this way, having a will becomes unnecessary. Since assets passing by a trust are not subject to probate as assets that pass by will are, distributions to beneficiaries can be made more quickly (and they are often needed quickly). Further, bypassing probate will save the grantor's estate any costs that would have otherwise been incurred, such as filing fees and attorney's fees. And, finally, the grantor's family will be spared any burden that would be associated with the probate process, such as petitioning the court and organizing documents for filing.

Caution: Bypassing probate may not be an appropriate goal for some individuals. For example, smaller estates may qualify for an expedited probate process or be exempt from probate altogether. In some cases, the costs associated with a living trust may be greater than the costs associated with probate. And, under certain circumstances, the court's oversight of the estate settlement during the

DISADVANTAGES

Does not save taxes

Though a living trust is a separate legal entity, it is not a separate taxpayer during the grantor's lifetime. The grantor is considered the owner of the trust assets for tax purposes. All income and expenses generated by trust property flow through to the grantor and must be reported on the grantor's personal income tax return. However, upon the grantor's death, the trust becomes a separate taxpayer and different income tax rules apply. Further, assets in the trust will be included in the grantor's gross estate, generally at their date of death value, for estate tax purposes. Therefore, a revocable living trust cannot be used as a way to minimize taxes.

Does not shelter assets from creditors

Generally, assets in a revocable trust are deemed to be owned by the grantor and are therefore reachable by creditors (although, in some states, the assets may not be reachable by Medicaid recovery after the look-back period expires).

IMPORTANT DISCLOSURES

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The Case for Hazard and Operability Methodology

There is a vigorous debate within the industrial refrigeration industry surrounding whether or not the use of hazard and operability methodology, referred to as HAZOP, should be considered the industry standard for hazard reviews and process hazard analyses. While there are advocates for and against employing HAZOP methodology, Stephanie Smith, senior engineer II with Risk Management Professionals Inc., said her research and experience show that the benefits generally outweigh the costs.

Smith made the comments while speaking during the IIAR 2021 Natural Refrigeration Conference & Expo virtual meeting.

The Center Chemical Process Safety defines the purpose of a HAZOP Study as to "carefully review a process or operation in a systematic fashion to determine whether deviations from the design or operational intent can lead to undesirable consequences."

Smith said HAZOP produces more comprehensive hazard reviews and process hazard analyses than other, more common methodologies, and provides more information specific to the location of system vulnerabilities, which may also result in focused recommendations that are specific and straightforward to address.

Other methodologies include what-if/checklists, failure mode and effect analysis (FMEA), and fault tree analysis. Smith said what-if/checklists tend to be more flexible, qualitative, and more general in evaluating hazards while HAZOP is more systematic, qualitative and identifies specific causes and failures. FMEA is about single-failure modes, is more qualitative, and is specific for equipment failure leading to an incident rather than human involvement. Fault tree analysis is even more advanced and specific and focuses on incidents for deriving causes and is more quantitative.

Currently, HAZOP and what-if/checklists are the most used methodologies in the industrial refrigeration industry and what-if/checklists can be used in conjunction with HAZOP.

When conducting a HAZOP study, the first step is to gather information. Smith said it is important to have good and updated piping and instrumentation diagrams (P&IDs), process safety information, and the team's input on operations and maintenance procedures implemented at the facility.

"Essentially when we do a HAZOP, we break the P&IDs down into nodes. The system is broken down into smaller nodes for the study. Then we look at parameters. What process parameters do we evaluate? We also look at guide words, which provide guidance on deviation from normal operations," Smith said.

In her technical paper on HAZOP, Smith wrote that guide words are used to lead the team through their discussions. Teams can develop scenarios under each set of guide words, examine the consequences of each scenario, discuss and document deviations from normal operating conditions, rank the severity of the consequence and identify safeguards. They can then rank the anticipated frequency accounting for the safeguards, develop recommendations to lower risk, if necessary, and then repeat for all scenarios and nodes.

The challenges of using the HAZOP methodology are multifold, but they can largely be mitigated by a facilitator who is experienced and conversant in the methodology. Smith said the facilitator's primary role is to guide the team to its own conclusions. Sometimes the conclusion is obvious, sometimes it can take hours or days of discussion and investigation to unearth.

Probably the most difficult role for a facilitator is to be a mediator for the methodology, ensuring that all team members understand the "rules" and appropriately address the agreed-upon hazard scenarios. Common struggles include trouble assessing severity without safeguards, identifying hazards outside the node/ scenario, disagreements between the design intent and actual function of the system, and recommendations lacking the specificity needed for the study. The facilitator must also understand the risk ranking methodology.

Smith said HAZOP studies can take more time than other methodologies, but that's to be expected for a more critical examination that requires additional time for discussing results.

Even still, Smith said the benefits of HAZOP far outweigh the challenges, and they can be enhanced by a facilitator who can lead the HAZOP team to a full understanding of the study itself and the resulting conversations. Plus, the more complex, quantitative methodology lends additional power to the study in that an ultimate consequence can be narrowed down to specific failures in the system without much additional effort. Ultimately, this information is more valuable than that provided by the most common methodologies used to evaluate ammonia processes, she explained.

The HAZOP methodology is systematic when it comes to discussing hazards, as it requires the team to identify each piece of equipment and each valve in the system, which makes the evaluation specific and thorough. Other methodologies generalize the brainstorming of hazards, which can lead the team to misjudge or even overlook hazards, Smith said.


RV
AMMONIA

RECOMMENDED PRACTICES

From Dry to Hybrid: A 360 Degree View of Cooling Technologies

Cooling technologies affect price and cooling capacity, and there are a variety of fundamentally different dry cooling technologies available for cooling water/glycol mixtures. The decision for or against one of these technologies during the planning stage of a project has an impact not only directly on the investment sum but also on the subsequent operating costs of the plant across the entire life cycle.

"It is a really important decision you make," said Michael Freiherr, chief technology officer for Guentner AG & Co. KG Guntner U.S., while speaking during IIAR's annual meeting.

> "It is a really important decision you make. … All of the different cooling technologies have very specific pros and cons."
>
> – Michael Freiherr, chief technology officer for Guentner AG & Co. KG Guntner U.S.

That means it is critical to know the applications of the technologies, as well as their specific advantages and disadvantages, and to evaluate them carefully. "All of the different cooling technologies have very specific pros and cons," Freiherr said.

During the session, Frieherr discussed several types of technologies, including dry, spray, adiabatic, and hybrid.

Dry Cooler: A dry coolant, as the name indicates, doesn't use any water. "Whenever you have issues with water treatment or hygiene reasons, or topics like lachenalia, the dry cooler is the system of choice," Frieherr said. "The downside is you need a large installation footprint for those types of units. If you don't have the footprint available, you can switch to spray or water-consuming technologies."

The dry cooler is the very best solution when it comes to water consumption because there is no water consumption, Frieherr explained. "The downside is you have bigger units compared to the wetted cooling technologies," he said.

"For the wetted cooling technologies, you have to deal with the water treatment because there are some rules to deal with and you need different water qualities for the different types of wetted technologies," he said. "If you deal with it and you take advantage of the wetted technology, there is a good portion of energy-saving and also cost-saving potential for you and your client."

Spray Coolers: Sprayed is in many ways identical to a dry cooler but is prepared for peaks in capacity or temperature with the spray system. They increase the energy efficiency ratios compared to the dry coolers. Spray coolers don't use as much water as the adiabatic or hybrid, but they can't achieve the power in terms of water outlet temperature. "If you want to go down with the water temperature, you need the adiabatic, hybrid, or cooling tower," Frieherr said.

However, water treatment is necessary for wetted cooling technologies, Frieherr said. "If you deal with it and you take advantage of the wetted technology, there is a good portion of energy-saving and also cost-saving potential for you and your client," he said.

Adiabatic: Adiabatic utilizes 'wetting pads' in front of the heat exchanger. The water is not directly applied to the heat exchanger itself but is evaporated on the wetting pads in the airstream before the air hits the heat exchanger. It can use lower quality water.

Hybrid: The hybrid dry cooler is fully optimized for long period in wet operation. It has the lowest footprint of the systems. However, the hybrid uses the most water. "The lower you want to go with your temperatures, the more water you will need for your unit," Frieherr said.

Each system has different operating costs. "Typically, the lower the temperature the higher the operating costs," Frieherr said.

As part of the case study, Frieherr said in the 104–113-degree Fahrenheit temperature range, the dry cooler had lower operating costs. However, for the 81-90-degree range, adiabatic had the lowest. "The operating costs are going down as your temperature goes down, but there are some specific differences. The hybrid dry coolers stand out on every temperature level," he said.

However, sometimes there are other factors for engineers to consider when developing projects, such as the footprint. For example, in the 104-113 temperature range, the dry cooler would have a footprint needed of 411 square feet. "At this level, it doesn't make sense to use spray or adiabatic due to cost, but it does if you need the space. Adiabatic is 151 square feet at this temperature level," Frieherr said.

On the other units, in the 81–90-degree range, adiabatic needs 936 feet whereas hybrid needs 269 square feet. "If you really want to have a very cost or energy-efficient plant with a very limited footprint available, the hybrid dry cooler is probably your only choice," Frieherr said.

The full session, From Dry to Hybrid: A 360 Degree View of Cooling Technologies, is available on IIAR's Natural Refrigeration Conference & Expo website.

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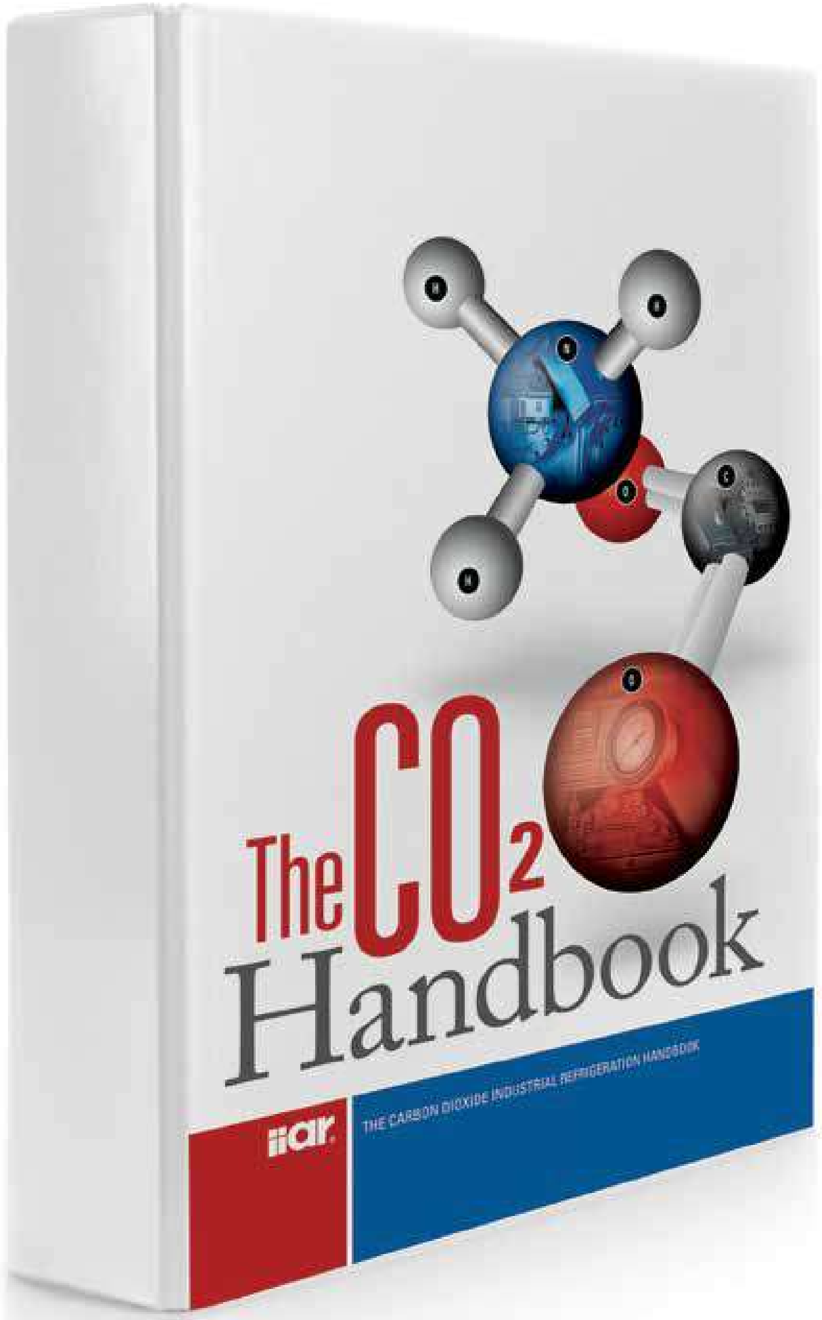

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A Great way to Learn

KEM RUSSELL

The following incident had many lessons learned for both the facility and the outside responders. Think about what would happen, or what actions would be taken if this happened at your facility.

Roy was backing up his forklift near the cherry processing line. And for whatever reason Roy didn't stop till the forklift slammed into piping for hydro-cooler # 4.

The impact completely separated the flange on the downstream side of the back-pressure regulator, allowing pressurized vapor to escape from both the associated surge drum as well as from the main suction line.

This being cherry season there were over 100 people in the large processing room. Those closest to the release point were quickly confronted with a very high concentration of ammonia vapor, and they immediately began to self-evacuate. Unfortunately, as anyone who has been around processing lines knows, many times there are no easy or fast ways to escape some areas. Almost all of the people escaping the area suffered injuries, not only from the ammonia concentration but as they hit stainless steel equipment and supports in their mad escape.

People on the east side of the packing line filling stations were forced to escape through the invisible vapor cloud due to equipment arrangement. All of these people had injuries to their eyes and respiratory tract.

Lesson to Learn: How can people escape from all areas during an ammonia release?

> **Unfortunately, as anyone who has been around processing lines knows, many times there are no easy or fast ways to escape some areas. Almost all of the people escaping the area suffered injuries, not only from the ammonia concentration but as they hit stainless steel equipment and supports in their mad escape.**

People along the sorting tables encountered strong-smelling ammonia vapors as they escaped, which caused them not to stay on their primary evacuation route.

The few Supervisors in the large room initially didn't know what was happening, until one of them got a smell of ammonia. The situation on the packing line had gone from orderly, to chaos in less than a minute.

A few minutes later one of the Supervisors who had gotten outside notified the refrigeration operator about the release near hydro-cooler #4. The refrigeration operator immediately used the control system to shut down the hydro-cooler zone. This action de-energized the liquid feed solenoid to the hydro-cooler surge drum, and also de-energized the back-pressure regulator pilot solenoid. At this time the refrigeration operator didn't know that due to the break location ammonia vapor was still releasing from the main system suction line.

Evacuation from the room was quick and soon people were outside and gathering at the assembly points. While a headcount was going on, one Supervisor called 911 explaining that they had an ammonia release and needed help. The 911 dispatcher already knew something was happening from the numerous previous calls from many escaping employees.

Lesson to learn: If people have cell phones they will call, which may be helpful, but can create confusion depending on the messages 911 receives.

Due to the situation, this quickly became a two-alarm event, calling in additional resources. After about 12 minutes from the 911 notification, firetrucks, and aid units began arriving at the scene. Fortunately, the Captain on the first in-engine had dealt with a few other ammonia incidents. Unfortunately, there was no hazmat response trained men among the responding groups, and outside assistance from State or Federal groups would be hours away.

Knowing the normal wind direction helped the first in-engine quickly establish a safe location to set up command. Also, having wind indicating flags on top of some of the light poles helped. However, the Fire Captain did mention that it was good that this incident happened during daylight since he had previously been at the facility in the dark and he couldn't see the flags on top of the light poles. Just the bright light.

Lesson to learn: Positioning of wind indicators matters.

The arriving responders were quickly overcome with patients, and this became an MCI "Mass Casualty Incident". The trained responders began separating people into Green, Yellow, and Red groups based on a quick assessment of a person's injuries. A "Black" tag would have been used for a fatality and at this point there were none. However, until the headcount could be completed, it was unknown if everyone had gotten out.

The refrigeration operator soon arrived at the command post and he and the Fire Captain started discussing what was happening and what could be done. The Fire Captain asked, "Is the ammonia leak stopped, and if not, how could it be stopped?" The operator replied that he had shut down the zone.

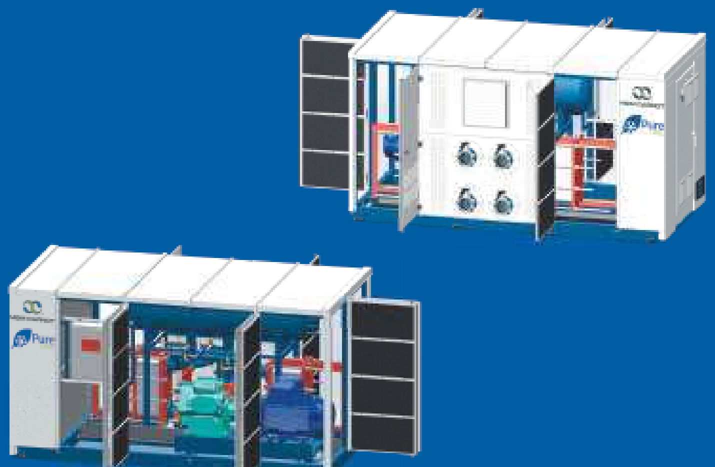
When the refrigeration operator said he had shut down the zone, the Captain immediately asked, "What's a zone?" The operator explained that using the control system he had turned off the liquid make-up and the suction control valve "BPR" to the equipment or zone that he had been told was the source of the release. The operator explained, "So if the liquid line and solenoid are not damaged that should stop any liquid. And with the BPR pilot off no vapor should be released until the pressure in the surge drum gets to about 85 psig."

"Anything else that could be done?" asked the Captain.

"I forgot, I also closed the King valve in the machine room," replied the refrigeration operator. "It won't take long before that zone and all the rest of the system runs out of liquid."

"I could also close the hand valves in the liquid and suction lines that lead to all of the hydro-coolers in the room, but I'm going to need help to do that. Those valves are located up high in the piping on the outside of the east side

The operator explained that using the control system he had turned off the liquid make-up and the suction control valve "BPR" to the equipment or zone that he had been told was the source of the release.



of the building. I need a scissor lift to get to the valves, and unfortunately, ours is in the shop. I can also lower the system suction pressure to pull down the zones."

"What do you mean by pull down?" asked the Captain.

Lesson to learn: Jargon difference, which training with the outside responders will help overcome.

"I'll lower the operating pressure of the compressors, which will remove more vapor from the system, which could help, depending on where the break is. If the suction line is open someplace, it won't take too long for enough air to be sucked into the system to raise the discharge pressure, and I will have to shut down the compressors," replied the refrigeration operator.

"Do what you can with the system, and we'll get a ladder truck so you can access those shutoff valves", said the Captain.

Another refrigeration operator went to the machine room to start the pump down, while a plan was developed to get to the shutoff valves. In the meantime, the headcount results were reported to the Captain. Everyone was accounted for, except Roy.

With plans in place to reduce and/or stop the ammonia release, they started developing a plan to ventilate the entire building. To do this "Positive Pressure Ventilation" (PPV) would be done using the high CFM gasoline-powered fans from several fire trucks. The challenge was determining what doors were open or closed within the facility. The memory of a couple of supervisors about possible door positions was the best information. The hope was to push the ammonia out an outside roll-up door, and not into other rooms within the facility.

By this time about 40 minutes had passed, and a hazmat response team from another company in the area had arrived on the scene. Their assignment was to search for the one missing person, Roy.

The incident described above didn't actually happen, but it could have. This was an ammonia release scenario used in a Dual County Table Top Exercise, in which the company that had the Cherry line was involved. Those attending the exercise were: Fire Departments who would be responding; 911 Dispatch; Law Enforcement; County Office of Emergency Management; State Department of Ecology Spill Response; Hazmat team representatives from the only company in the area that had hazmat response capability; and an ammonia specialist. A representative of the Office of Emergency Management worked as an overseer to keep all groups on task through the various stages of the table top exercise. The entire exercise lasted 1.5 hours and was video recorded for people and groups who couldn't attend.

This table top exercise resulted in all that were involved learning things they could do better should an actual ammonia incident occur, as well as many things they hadn't thought of before. Table Top Exercises can be a valuable method in helping companies and responders be better prepared for any kind of ammonia incident. Large or small. Use them.

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Identifying and Quantifying Fugitive Emissions from Industrial Refrigeration Systems

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ABSTRACT

Industrial ammonia refrigeration systems vary widely in their engineering design, size, scope, and technology features. However, they universally experience some level of refrigerant loss throughout their operational life. Refrigerant losses from industrial ammonia refrigeration systems originate from any number of sources including uncontrolled releases from incidents and accidents, intentional releases during maintenance activities, and fugitive emissions.

This paper discusses methods for finding and quantifying fugitive emissions of ammonia from industrial refrigeration systems with the goal of reducing refrigerant losses that occur from these systems. From the outset, the working hypothesis is that fugitive emissions represent a significant contribution to the overall refrigerant loss rate for industrial refrigeration systems. Since there has not been an organized effort to identify and quantify fugitive emissions associated with industrial ammonia refrigeration systems, this hypothesis needed to be tested as a prerequisite to establishing approaches to reduce refrigerant losses.

Field work identifying and quantifying refrigerant losses, including fugitive emissions, was performed on six (6) industrial ammonia refrigeration systems located at five (5) plants. A total of one-hundred seventy-five (175) components were surveyed with one hundred fifty-nine (159) scanned and one hundred ten (110) bagged for emission collection. For components surveyed with measurable refrigerant fugitive emissions, the average leak rate was 0.086 lbm/year [39 gram/year]. The average of all sampled components was 0.035 lbm/year [16 gram/year]. If a hypothetical refrigeration system is comprised of 1,000 components leaking at this average fugitive emission rate, the total refrigerant loss from fugitive emission for this system would total 35 lbm/yr [16 kg/yr]. Comparatively, the average annual total refrigerant purchased for the plants surveyed was 1,660 lbm/yr [755 kg/yr]. Based on these findings, fugitive emissions, as a refrigerant loss category, are not a significant contributor to annual refrigerant loss. The two categories of refrigerant losses that appear to more meaningfully contribute to the annual total are accidental releases and intentional venting in conjunction with servicing and maintenance activities. No specific assessments for these two loss categories were systematically conducted as part of the present study so these loss categories were not separately tracked. Also proposed is a method for dynamically tracking the quantity of refrigerant in a system as a means of highlighting occurring losses so staff can find and repair the leak source more promptly than current practice.

Introduction

Fugitive emissions: The unintended loss of refrigerant from a refrigeration system that goes undetected.

Refrigerant losses from refrigeration system sources including accidental releases, venting during maintenance, and fugitive emissions occur during normal operation. Section 608 (40 CFR Part 82, Subpart F) of the Clean Air Act mandates that losses of ozone-depleting fluorochemical refrigerants used in industrial systems be under 30% per year as a threshold that triggers owners to pursue refrigeration system leak repairs. Because ammonia has no ozone-depletion potential, it is not subject to the regulatory requirements of Section 608. Nonetheless, there is interest within the natural refrigeration community to reduce losses of ammonia from refrigeration systems as a means of pollution prevention, risk mitigation, and reducing refrigerant replenishment costs.

For over a decade, the University of Wisconsin-Madison Industrial Refrigeration Consortium (IRC) has gathered anecdotal evidence from the field that indicate industrial refrigeration systems exhibit a wide variation in annual refrigerant losses that range from 1% to more than 100% per year. This wide variation raises several questions. Why is the annual refrigerant loss rate so variable from system to system? What is the origin of refrigerant loss from these systems and is there a common thread that enables the losses? Is there a reasonable threshold for annual refrigerant losses that could be applied to industrial refrigeration systems? To what extent do fugitive emissions contribute to the overall annual refrigerant loss rate for industrial systems? Answering these questions served as motivation for this project.

Losses of refrigerant from vapor compression-based refrigeration systems can be categorized as “known” or “unknown.” Known losses can be either quantified or unquantified. Known losses from ammonia refrigeration systems include moderate-to-large accidental releases as well as venting of ammonia as a part of maintenance activities. In these cases, facility personnel are aware or know that a refrigerant loss has occurred. In an accidental release, end-users must quickly determine if the quantity of refrigerant released exceeds the reportable quantity threshold of 100 lb_m [45.4 kg] for anhydrous ammonia so appropriate notifications can be contacted. At the federal level, 40 CFR 302 and 40 CFR 355 establish notification requirements related to accidental refrigerant releases, while some states and local jurisdictions have additional reporting requirements. During an incident investigation of an accidental release, end-users will often refine the initial estimate of refrigerant quantities released. Known losses that are rarely quantified relate to smaller, incidental mechanical integrity failures of seals or joints, or ammonia that is discharged or vented during system maintenance activities.

Unknown losses include fugitive emissions and accidental leaks/spills that do not rise to the level of triggering an alarm or other notification system. This paper reports on a project that examines the prevalence of fugitive emissions in industrial ammonia refrigeration systems and assesses their total contribution to the overall losses a given refrigeration system may experience on an annual basis (Reindl, et al. 2020a).

In some cases, unknown losses can be masked or hidden by an intervening media. Two classic examples of ammonia losses that can occur over relatively long periods of time before being discovered are evaporative condenser tube leaks and losses through malfunctioning autopurgers. In both cases, the “intervening media” is water. Because evaporative condensers circulate water over the outside of the refrigerant heat exchanger, smaller refrigerant leaks from the heat exchanger are readily absorbed into the condenser water. In the case of an autopurger, non-condensable gas (primarily, air) is directed through a water column to absorb expected trace amounts of ammonia vapor that co-exist with the non-condensable gas being expelled from the air separation chamber of the autopurger. In cases where the autopurger malfunctions, larger amounts of ammonia can be discharged from the purger with the water column masking the release by absorbing the ammonia.

Principles and Technologies for Finding Fugitive Emissions

Given that loss rates are often extremely small, fugitive emissions are difficult to find. In the sections that follow, we discuss approaches and equipment that can be used to locate refrigerant leaks, even in cases where no ammonia odor is readily detectable. More importantly, we show methods of measuring fugitive emissions to quantify leakage rates.

Detecting Ammonia Leaks

Locating and repairing small refrigerant leaks is an important part of safely operating any process, particularly one in which the refrigerant poses a hazard. Even small refrigerant leaks can indicate a variety of system issues, from a loss of mechanical integrity to malfunctioning safety systems to inadequate routine repairs. Small refrigerant leaks are most often discovered by qualitative means such as odor, with subsequent use of sulfur sticks or an ammonia detector to pinpoint the location. There are techniques that can quantitatively measure rates of refrigerant loss from small leaks, including fugitive emissions.

Qualitative Leak Detection

The most common way of detecting ammonia leaks is by the presence of ammonia's distinct odor. Once the odor is discovered or reported, plant personnel will follow-up and pinpoint the leak source using simple tools such as a sulfur stick or litmus paper. Sulfur sticks consist of a wick material covered with a sulfur-laced wax. When the wick is lit and burning, sulfur liberated by the flame will react with airborne ammonia to produce ammonium sulfate which results in a distinct white wispy cloud appearance that will help the responding technician locate the leak source. Some technicians prefer to rub wetted litmus paper along potential leak sites. The presence of ammonia will cause the litmus paper to turn blue, with a darker color change correlating to a higher ammonia concentration due to the alkaline nature of ammonia.

Ammonia leaks can be detected in the air using a variety of detector technologies such as chemical, photoionization, catalytic bead, and infrared. These technologies are commonly deployed in both handheld and fixed devices. For this project, a handheld ammonia detector was used to quantification refrigerant leaks in a process referred to as “screening.”

Screening involves holding the ammonia detector, preferably with an onboard sampling pump and probe, close to the potential leak site (gasketed connections, screwed connections, stem packing, etc.). This approach can identify a location with ammonia concentration at or above the sensor’s limit of detection. An example setup is shown in Figure 1, where a sight glass is being screened for ammonia leakage by using the detector’s sampling probe to carefully traverse the face of the glass and retaining ring to “sniff” for the presence of ammonia. If ammonia is detected, the component is then bagged to quantify the actual leak rate.

Figure 1. Refrigerant detector equipped with an integral vacuum pump to screen for refrigerant emission from a sight glass in the field.

Fixed-mount refrigerant detectors enable remote monitoring of locations that contain refrigeration. In the event of a refrigerant release, ammonia sensors provide a warning to personnel for safety, trigger engineering controls, and alert plant personnel so the leak can be mitigated. In some cases, measured airborne concentrations of ammonia can be used to estimate release quantities during subsequent incident investigation activities.

Likewise, handheld detectors are used to monitor concentrations during response or maintenance activities for safety purposes. Although not required by industry codes and standards, many plants have deployed ammonia detectors within pressure relief vent-line piping to alert plant personnel if a relief valve has actuated. The sensors used in this application typically require a comparatively high limit of detection (4,500 ppm or higher). The high detection limit for relief vent line sensors may not detect if one or more relief valves may be exhibiting fugitive emissions via refrigerant weeping through valve seats.

Another potential means of identifying leaks is the use of thermography. Gas detection thermography relies on filtering the specific infrared wavelength emitted by the gas molecule being targeted and highlighting those wavelengths on a user screen. An uncooled, gas-specific prototype unit was employed during this project. The camera was used to visualize controlled leaks from a cylinder of anhydrous ammonia. The camera could readily detect leaks at comparatively high release rates on the order of 9.8 lb_m/day [4.4 kg/day]; however, we did not experiment with identifying a lower limit of detection for much lower leak rates more typical of fugitive emissions. The release rates required to identify flow on the screen far exceeded the odor threshold and could easily be picked up using alternative means such as an ammonia detector or sulfur stick.

Finally, ultrasonic detectors are commonly used to pinpoint leaks in compressed air systems. We evaluated this technology for its potential application to locate and quantify ammonia vapor leaks; however, we concluded it is not sufficiently sensitive to detect the low leak rates associated with fugitive emissions.

Quantitative Leak Detection

Once identified, fugitive emissions of ammonia were measured in the field by bagging. Bagging involves enclosing a leak site within a plastic bag and inducing a flow through the bag across the leak site, as shown in Figure 2. A schematic of bagging setup used for larger leak rates during the project is shown in Figure 3.

Figure 2. Shutoff valve on the high-pressure side of an ammonia refrigeration system (left) being bagged (right) to quantify refrigerant leakage from the bonnet gasket or stem packing.

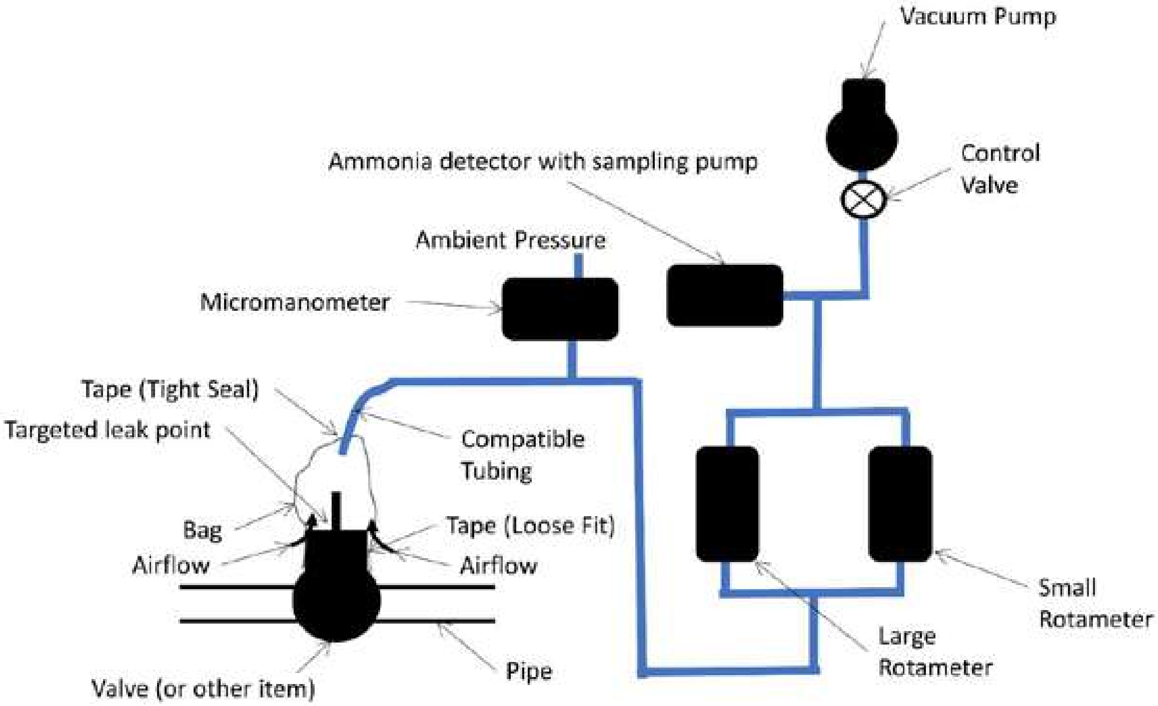


Figure 3. Diagram of the bagging setup used in the field.

The following provides a method for calculating the leak rate for a bagged component wherein the microenvironment within the bag is being sampled with an ammonia detector using a known gas flow rate, measured concentration, local atmospheric pressure, and local temperature (EPA, 1995, pp. 4-9).

$$\text{Leak Rate}\left(\frac{\text{lb}_\text{m}}{\text{year}}\right) = \frac{0.000817 \cdot \text{Q} \cdot \text{MW} \cdot \text{GC} \cdot \text{P}}{\text{T} + 459.7}$$

$$\text{Leak Rate}\left(\frac{\text{kg}}{\text{year}}\right) = \frac{9.63 \times 10^{-6} \cdot \text{Q} \cdot \text{MW} \cdot \text{GC} \cdot \text{P}}{\text{T} + 273.15}$$

where:

0.000817 is a conversion factor for ideal gas flow: $\frac{\text{lbmol} - \text{R} - \text{in}^2 - \text{hr}}{\text{ft}^3 - \text{ppm} - \text{lb}_\text{f} - \text{yr}}$

9.63×10^{-6} is a SI conversion factor for ideal gas flow: $\frac{\text{K} \times 10^6 - \text{kg}_\text{mol} - \text{min}}{\text{liter} - \text{hr} - \text{mmHg}}$

Q is the gas flow rate through the ammonia detector in ft^3/hr [liter/min]

MW is the molecular weight of the refrigerant in $\text{lb}_\text{m}/\text{lb}_\text{mol}$ [$\text{kg}/\text{kg}_\text{mol}$], ammonia is 17.03

GC is the measured gas concentration in ppmv

P is the local atmospheric pressure in psia [mmHg]

T is the local temperature in °F [°C]

Bagging was found to be an effective way to measure a wide range of refrigerant release rates because the air flow through the bag can be controlled using a vacuum pump to maintain the mixture within the ammonia detector readable range. The ammonia detector used during this project is equipped with two (2) separate sensors: a photo ionization detector (PID) for sensing lower concentrations of ammonia (0-1,000 ppm) and a catalytic bead sensor for detecting higher concentrations of ammonia (4,500 -150,000 ppm). Figure 4 shows the effective leak rate measurement range as a function of ammonia concentration over the range of the PID sensor.

At the upper limit of detection for the PID sensor (1,000 ppm), the maximum leak rate corresponds to 0.38 lb_m/yr [0.17 kg/yr]. Figure 5 shows the effective leak rate measurement range as a function of concentration for the catalytic bead sensor. In this case, the lower limit of detection for this sensor is 3% of the lower flammability limit (LFL, 4,500 ppm) and the corresponding lowest leak rate is 1.8 lb_m/yr [0.82 kg/yr]. Because the handheld ammonia detector has its own fixed-speed sampling pump, decreasing the sampling pump's flow rate is not an option, as the unit alarms and requires a pump restart when a decrease in gas flow rate is detected. Without the use of a separate vacuum pump to dilute the bagged concentration of ammonia by increasing airflow, there is a gap in leak rate measurement capability using the handheld detector alone.

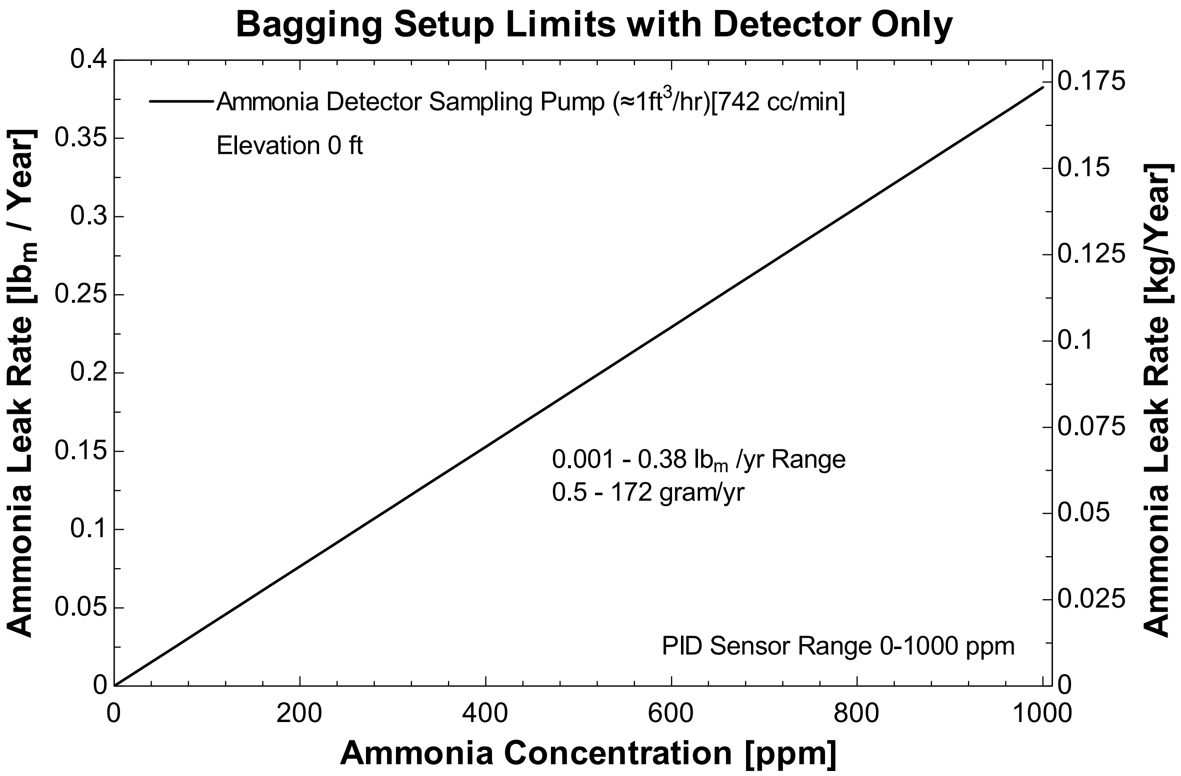


Figure 4. Ammonia leak rate as a function of sensed concentration within the detection limits of the PID sensor for a bagging setup.

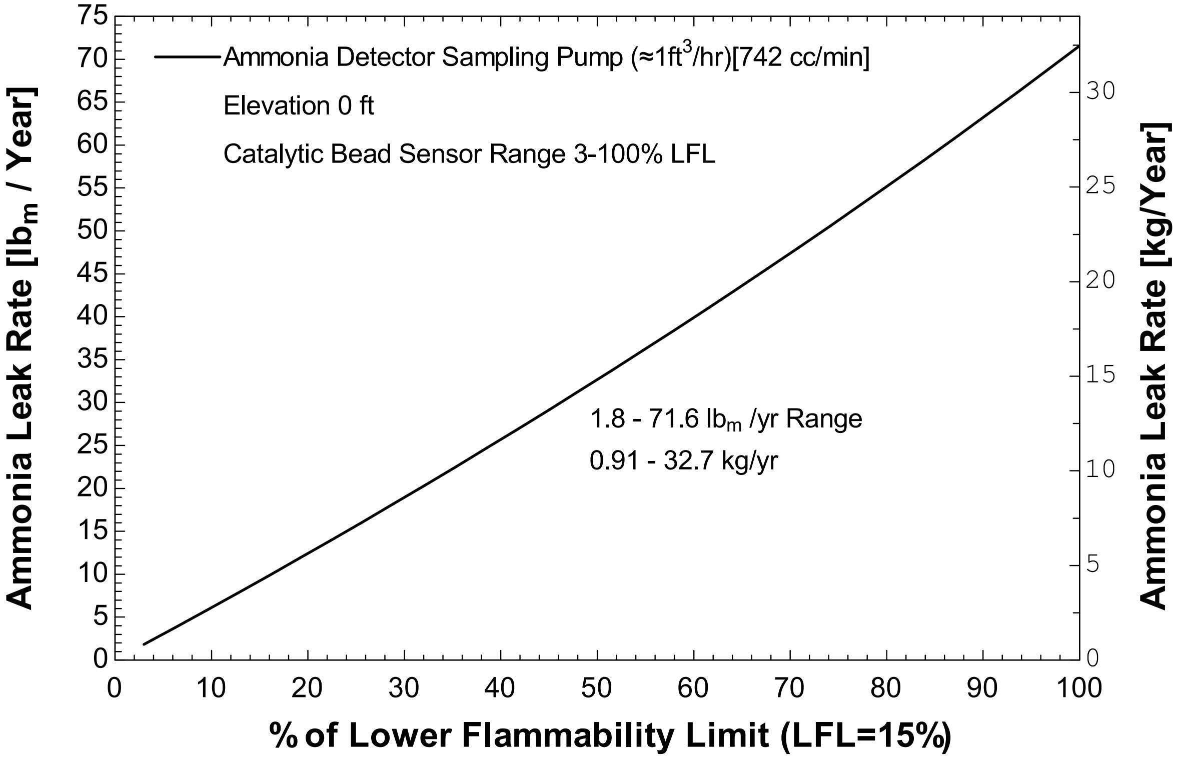


Figure 5. Ammonia leak rate as a function of sensed concentration within the detection limits of the catalytic bead sensor for a bagging setup.

A wider range of leak rates can be measured when a separate vacuum pump is deployed, as quantified in Figure 6 and Figure 7 and summarized in Table 1. The separate vacuum pump allows a greater flow rate of ambient air to be drawn through the bagged component to further dilute the ammonia concentration within the bag's microenvironment. Varying the flow rate allows for coverage of the gap noted previously, and extends the measurement range up to 2,000 lb$_m$/yr [907 kg/yr] of ammonia vapor. For liquid leaks, other means must be used to measure the liquid release rate. Refer to IRC (2020b) for further details on measuring leak rates using a handheld detector alone or in conjunction with a separate vacuum pump.

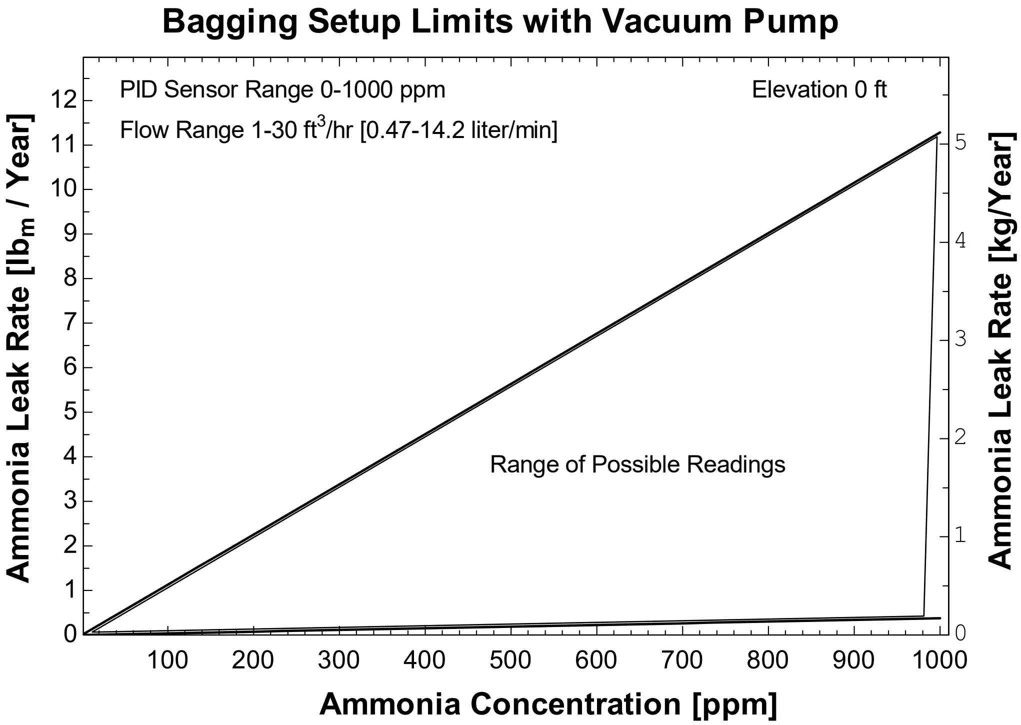


Figure 6. Bagging setup limits with PID sensor and vacuum pump.

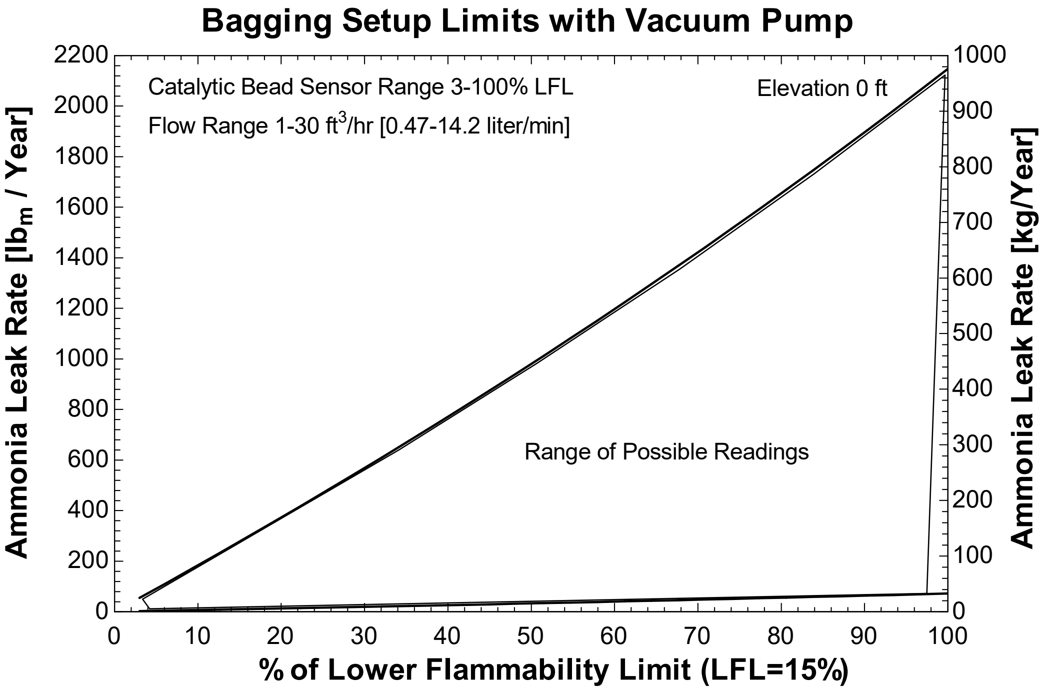


Figure 7. Bagging setup limits with LFL sensor and vacuum pump.

Multiple sources contribute to the uncertainty in measuring fugitive emission leak rates. A relatively small contribution in uncertainty comes from variations in ambient temperature, humidity, and altitude. The primary source of uncertainty is the measurement of the total gas flow rate. The leak rate uncertainty due to the gas flow meter decreases as the flow rate increases. Two (2) rotameters were used during the project included a 0-1,000 cc/min unit and a 0-20 L/min unit, and the uncertainty for these flow meters is lowest when the gas flow is kept in the top half of the scale for each.

		Leak Rate Measurement Range (lb_m/year) [kg/year]	
Sensor	Detection Range	Onboard Pump (1 ft^3/hr) [742 cc/min]	External Vacuum Pump (1-30 ft^3/hr) [0.47-14.2 L/min]
PID	0-1,000 ppm	0.001-0.383 [0.00045-0.174]	0.001-11.3 [0.00045-5.13]
Catalytic Bead	3-100% LFL (4,500-150,000 ppm)	2-72 [0.91-32.7]	2-2,150 [0.91-975]

Table 1. Summary of fugitive emission leak rate ranges during bagging at sea level pressure.

Fugitive Emissions: Field Experience and Findings

Field work conducted at five (5) facilities included a total of six (6) refrigeration systems. Table 2 summarizes key characteristics for each of the plants and their refrigeration systems. Detailed refrigerant inventory calculations were performed for each system to establish benchmarks for their “maximum intended refrigerant inventory.” An analysis of historical ammonia purchases was performed to estimate the annual refrigerant loss rate.

The smallest system was Plant #4, with an operating refrigerant inventory of 5,382 lb_m [2,441 kg], while Plant #3 was the largest with a refrigerant inventory of 38,712 lb_m [17,559 kg]. The annual refrigeration loss estimate for Plant #4 is based solely on ammonia purchases totaling 2,166 lb_m [982 kg] (40.3%). However, this plant was undergoing an expansion with significant piping modifications still in progress during the time of our plant visit, so the refrigerant purchases are not solely reflective of refrigerant losses. Plant #3 provided a good estimate of the annual refrigerant loss quantity at 1,838 lb_m [834 kg] (4.8%) because no significant modifications have been made to this system over the time period analyzed.

Plant	System Charge (lb_m) [kg]	Annual losses (lb_m [%]) [kg]	Comments
#1	7,500 [3,402]	496 [6.6] [225]	Minimal system changes, reasonable loss est.
#2	15,726 [7,133]	2,369 [15.1] [1,075]	NH_3 additions are due to system expansion biasing apparent loss rate. Estimated steady state loss rate is approximately 4.8%/yr.
#3	38,712 [17,559]	1,838 [4.8] [834]	Minimal system changes, reasonable loss est.
#4	5,382 [2,441]	2,166 [40.3] [983]	Plant expansions are biasing apparent loss rate higher than expected. Significant equipment/piping replacements recently completed are expected to reduce annual losses.
#5 (System A)	27,571 [12,506]	1,594 [5.8] [723]	System recently underwent consolidation.
#5 (System B)	15,629 [7,089]	1,518 [9.7] [689]	
Totals	110,520 [50,131]	9,981 [9.0] [4,527]	Loss totals are biased high by 3 of 5 plants

Table 2. Key characteristics for six refrigeration systems surveyed during the field-phase of this project.

The primary purpose of conducting field work at the facilities was to find and quantify fugitive emissions of ammonia. A total of one-hundred seventy-five (175) different refrigeration system components were surveyed, including one-hundred fifty-nine (159) screened and one-hundred ten (110) bagged. Of the 175 components, a total of thirty-four (34) items had detectable refrigerant emissions, made up of twenty-one (21) sight glasses, twelve (12) system operating valves, and a compressor housing. Unexpectedly, the threaded connections, unions, flare fittings, flanges, check valves, plugs and pressure relief valves surveyed exhibited no fugitive emissions. Items with no detectable emissions were assumed to have a release rate below the lowest detectable level for this setup at 0.001 lb_m/yr [0.5 gram/yr].

The average leak rates found during the present study are summarized below in Table 3. Although somewhat arbitrary, a pressure of 80 psig [552 kPa_g] was chosen as the transition from what was considered "low" pressure to "high" pressure. Nominally, the qualitative flags for "low" and "high" pressure correspond to the refrigeration system's "high-side" and "low-side."

In an ammonia refrigeration system during normal operation, condensing pressures below and refrigeration loads above 80 psig [552 kPa_g] are quite rare. For the facilities surveyed, the highest refrigeration evaporator pressure was 60 psig [414 kPa_g], while the lowest condensing pressure observed was 110 psig [758 kPa_g]. The "Average Leak Rate" for "All Equipment" corresponds to the one-hundred ten (110) bagged components. The "Zero Odor Rate" corresponded to the average leak rate of bagged components where ammonia was detected during the bagging process, but no ammonia odor was noticed by the staff member conducting the screening/bagging. The "Zero Screen Rate" is the average leak rate of bagged components which recorded a zero (0) screening value. Clearly, the leak rates on a per-equipment basis are quite low and, collectively, they did not approach the actual total refrigerant loss rate from each of the five facilities where field work was conducted. For a complete list of survey results, refer to IRC (2020a).

Type	Pressure Level	Average Leak Rate (lb_m/yr) [g/yr]	Zero Odor Rate (lb_m/yr) [g/yr]	Zero Screen Rate (lb_m/yr) [g/yr]
All Equipment	All	0.035 [16]	0.002 [0.9]	0.001 [0.5]
	High	0.061 [28]	0.002 [0.9]	0.001 [0.5]
	Low	0.002 [0.9]	0.001 [0.5]	0.001 [0.5]
Valves	High	0.053 [24]	0.002 [0.9]	0.001 [0.5]
	Low	0.001 [0.5]	0.001 [0.5]	0.001 [0.5]
Sight Glass	High	0.090 [41]	0.004 [2]	0.002 [0.9]
	Low	0.001 [0.5]	0.001 [0.5]	0.001 [0.5]
Compressor Housing	All	0.009 [4]	-	-
Threaded Connections	All	None Detected (0.001) [0.5]	-	-
Flange Connections	All	None Detected (0.001) [0.5]	-	-
Plugs	All	None Detected (0.001) [0.5]	-	-
Pressure Relief Valves	All	None Detected (0.001) [0.5]	-	-

Table 3. Summary of fugitive emissions field survey results.

All plants had at least one component with fugitive emissions; however, we concluded fugitive emissions themselves did not rise to a level that accounts for significant refrigerant losses occurring for these refrigeration systems. For components surveyed with measurable refrigerant fugitive emissions, the average leak rate was 0.086 lb_m/yr [39 gram/yr]. The average of all sampled components was 0.035 lb_m/yr [16 gram/yr]. As an example, consider a given system with 1,000 components leaking at that average rate, the, fugitive emissions would total 35 lb_m/year [16 kg/yr], yet the average annual total refrigerant losses for the five plants surveyed had apparent losses that were two orders of magnitude higher at 1,664 lb_m/yr [755 kg/yr]. **Based on our findings, fugitive emissions are not a significant contributor to the overall loss of refrigerant from industrial ammonia refrigeration systems.** It appears that the two (2) categories of refrigerant losses that most meaningfully contribute to annual losses are accidental releases (small and large) and venting during system maintenance and repair.

Leak Rate Estimation of Small Releases

To relate screening values to actual emissions rates, a least squares regression, analogous to that of the EPA (1995), can be used. Ideally, this regression is prepared for each type or category of equipment; however, the equipment-specific instances of fugitive emissions found only produced enough data for regression of refrigerant sight glasses found on the high-pressure side of refrigeration systems. These sight glasses then dominated the regressions for both “all equipment” and “high-side equipment” categories.

The regression for screening all equipment using an ammonia detector drawing ~1 ft^3/hr [472 cc/min] through the sampling pump is shown in Figure 8. It would be expected that refrigerant detectors with higher gas flow rates would yield lower screening values for the same leak point due to dilution, and higher screening values for lower flow rate detectors due to less dilution. The actual relationship would need to be investigated further if a screening/bagging relationship is needed for other ammonia detectors or sampling flow rates. Most screening was conducted by moving the refrigerant detector’s probe tip in the immediate vicinity of the leak site while avoiding obstructing the probe and moving at a rate to accommodate the detector response time. Retracting the detector probe tip any distance away from the leak site creates lower screening readings for a given leak rate due to dilution of the sample drawn. Many small releases are not estimated due to the time required to directly measure the release rate coupled with the urgency of stopping known releases. Utilizing a least squares regression provides a fast, easy way to estimate release rates prior to repair, allowing facilities to better understand losses from these releases.

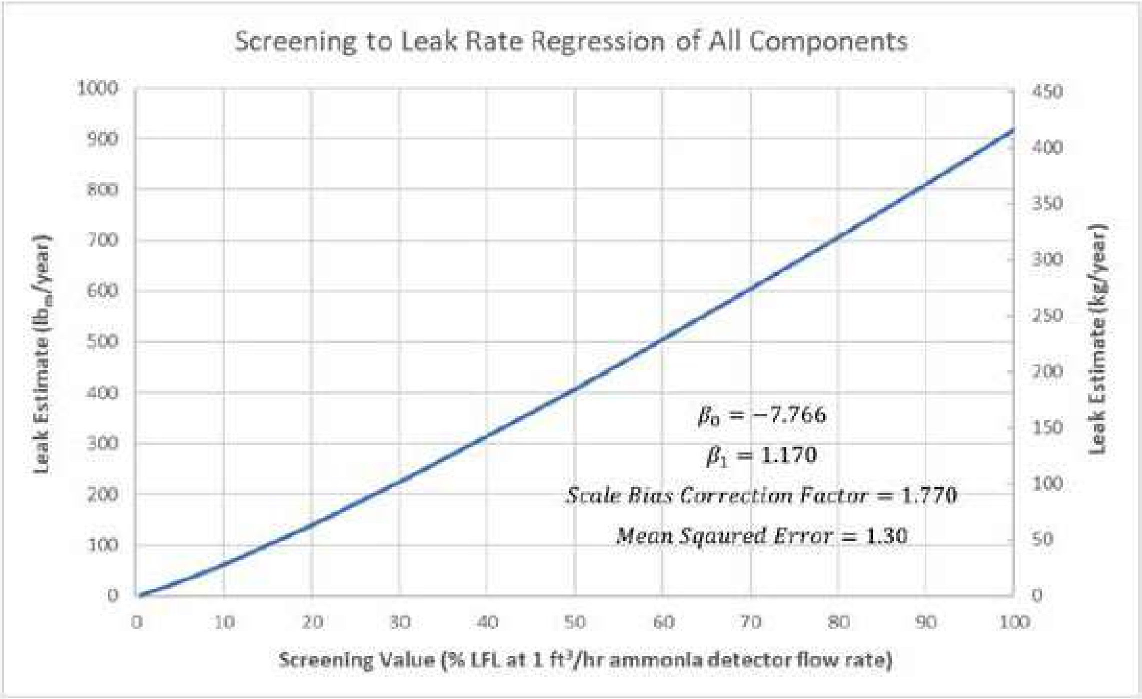


Figure 8. Least squares regression of the screening and bagging values of all equipment for the ammonia concentration range from 0-150,000 ppm, the range of the LFL detector.

Dynamic System Inventory Tracking

The periodic addition of refrigerant to systems will equal the refrigerant losses during the interval unless the system has had components added or removed from the system, and the refrigerant level after the addition results in the same refrigerant levels in the system's vessels. The concept of dynamically tracking the refrigerant inventory for the system over time can result in the ability to identify refrigerant losses. Because this is happening over time, losses can be noticed earlier than when compared to the lagging indicator of periodic purchase and addition of refrigerant to the system. Since industrial refrigeration systems may go one or more years between ammonia additions, a means of tracking refrigerant losses over a shorter time horizon would be desirable.

As refrigerant is lost or removed from the system and refrigerant inventory declines, the decline may be detectable by examining the inventory of refrigerant in a portion of a refrigeration system that has an uncontrolled refrigerant inventory. In most systems, this is the high-pressure receiver (HPR), as illustrated in Figure 9. Since the liquid refrigerant level in the HPR can fluctuate as refrigeration system operating conditions change, several liquid refrigerant level data points over days or weeks are required to begin establishing a clear trend in system refrigerant inventory. This technique is most effective for plants that have consistent operational profiles and where HPR level data are collected during periods of normal operation.

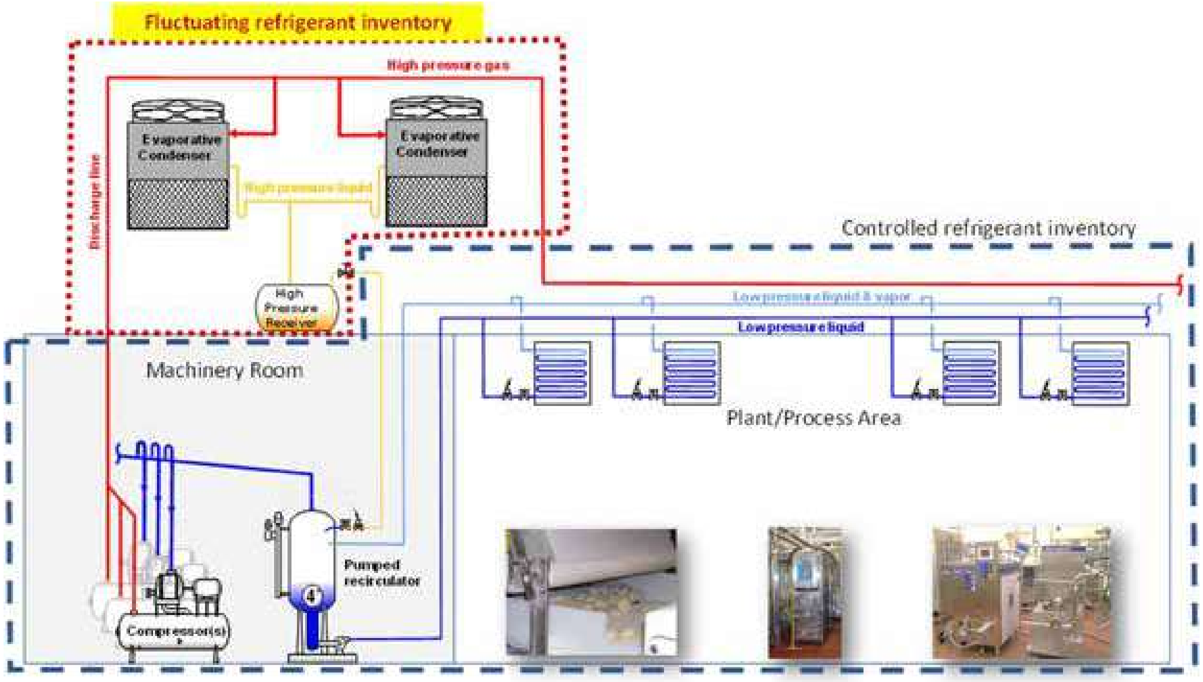


Figure 9. Zone of a typical industrial refrigeration system that characterized by fluctuating refrigerant inventory and controlled refrigerant inventory.

The HPR vessel operates at the system's condensing pressure, and the amount of refrigerant in the HPR is driven by system dynamics with no active controls used to manage the HPR liquid refrigerant level. The dynamic system inventory tracking method presented here relies on these refrigeration system dynamics to average out over time so a clearer trend in refrigerant system inventory emerges.

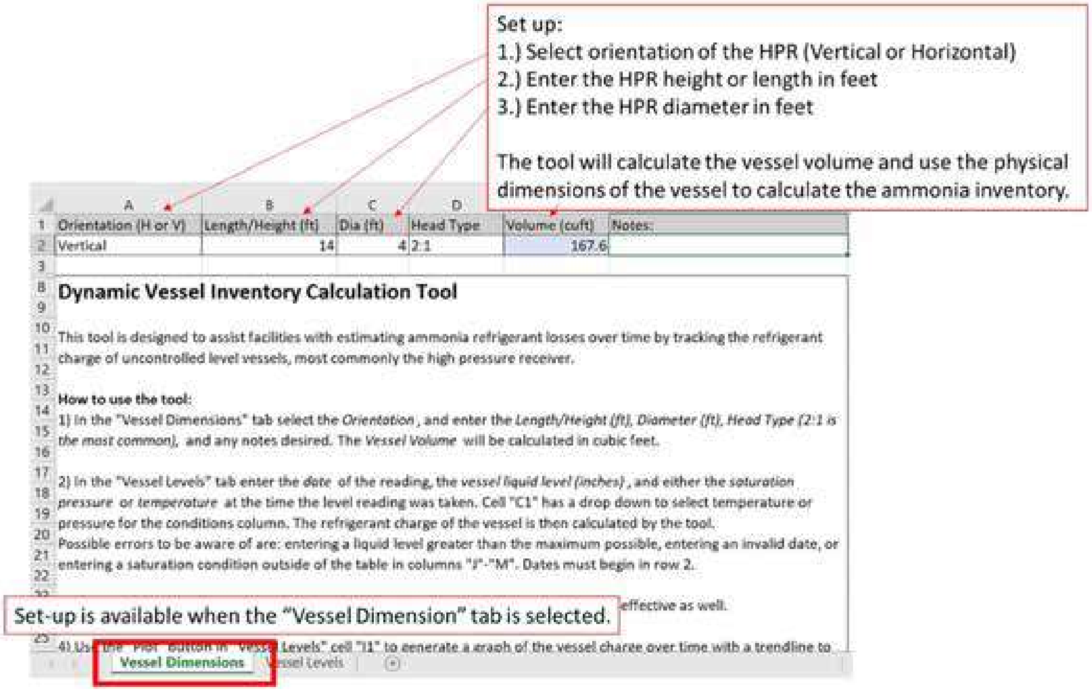
The first step in tracking the dynamic system inventory for a plant is to calculate the total amount of refrigerant contained within that system. This is usually referred to as the "maximum intended inventory" or "refrigeration system charge." Calculating the inventory requires accounting for all refrigerant contained within all vessels, piping, evaporators, condensers, and any other components that make up the refrigeration system. More guidance on conducting a refrigerant inventory calculation is provided in a separate document, IRC (2020b).

The next step is to determine which vessels will show trend in refrigerant loss. A basic system layout is shown in Figure 9 and is representative of many industrial ammonia refrigeration systems. The dashed lines shown in the figure divide the system into two parts: “controlled refrigerant inventory” and “fluctuating refrigerant inventory.” In the controlled inventory portion of the system, the refrigerant flows and liquid levels are actively managed. Pumped recirculation vessels and surge drums attached to gravity flooded evaporators are controlled to maintain a liquid level setpoint. Refrigerant make-up to these vessels is started or modulated as the level falls below setpoint and stopped when levels rise above setpoint. Evaporators tend to run with a relatively constant inventory during their normal cooling mode. As discussed earlier, the high-pressure receiver (HPR) does not operate at a controlled or fixed refrigerant level. As a result, the HPR is variable and will typically be the first vessel to indicate a dynamic trend in lower liquid levels when ammonia is lost from the system.

Every refrigeration system is unique, and some system designs/layouts may have more than one pressure vessel that must be incorporated into the “fluctuating inventory” portion of the dynamic charge calculations in order to provide a more accurate estimate loss the rate of refrigerant leaving the system. This can include systems with multiple high-pressure receivers; low-side vessels that vary in level such as accumulators (i.e., suction traps); or low-side vessels with variable level setpoints. Once the uncontrolled vessel(s) have been identified, the vessel size(s) must be measured or otherwise obtained from documentation to calculate the vessel’s refrigerant inventory for a given liquid refrigerant level. Once these items have been established, the dynamic inventory tracking can begin.

The dynamic inventory tracking involves periodically (e.g., daily) logging the liquid level in the HPR. The liquid level in a vessel is usually expressed as the liquid height from the bottom of the vessel as the reference point. This process is often accomplished during operator “rounds” performed at, nominally, the same time each shift or day. Preferably, the refrigeration system is operating normally at the time the liquid level is logged. If the HPR vessel level is logged multiple times a day, each log entry can be used in the inventory tracking, or the levels can be averaged to yield a single daily level.

A dynamic inventory tracking tool was created to facilitate the process of trending refrigerant losses occurring with an ammonia refrigeration system. The process begins with entering the orientation and dimensions of the system's HPR as shown in Figure 10. Upon completing the initial setup, the user would click on the "Vessel Levels" tab to enter collected data. Figure 11 shows the "Vessel Levels" tab with an example of the data entry for the tool that includes date, liquid level, and the system condensing pressure for each log condition entry. For each entry, the tool automatically calculates the information shaded in blue, including liquid and vapor density for ammonia, liquid and vapor volume, and total quantity or charge of ammonia in the HPR based on vessel dimensions and properties of ammonia.



Set up:
1.) Select orientation of the HPR (Vertical or Horizontal)
2.) Enter the HPR height or length in feet
3.) Enter the HPR diameter in feet

The tool will calculate the vessel volume and use the physical dimensions of the vessel to calculate the ammonia inventory.

Orientation (H or V)	Length/Height (ft)	Dia (ft)	Head Type	Volume (cuft)	Notes:
Vertical	14	4	2:1	167.6	

Dynamic Vessel Inventory Calculation Tool

This tool is designed to assist facilities with estimating ammonia refrigerant losses over time by tracking the refrigerant charge of uncontrolled level vessels, most commonly the high pressure receiver.

How to use the tool:
1) In the "Vessel Dimensions" tab select the *Orientation*, and enter the *Length/Height (ft), Diameter (ft), Head Type (2:1 is the most common),* and any notes desired. The *Vessel Volume* will be calculated in cubic feet.

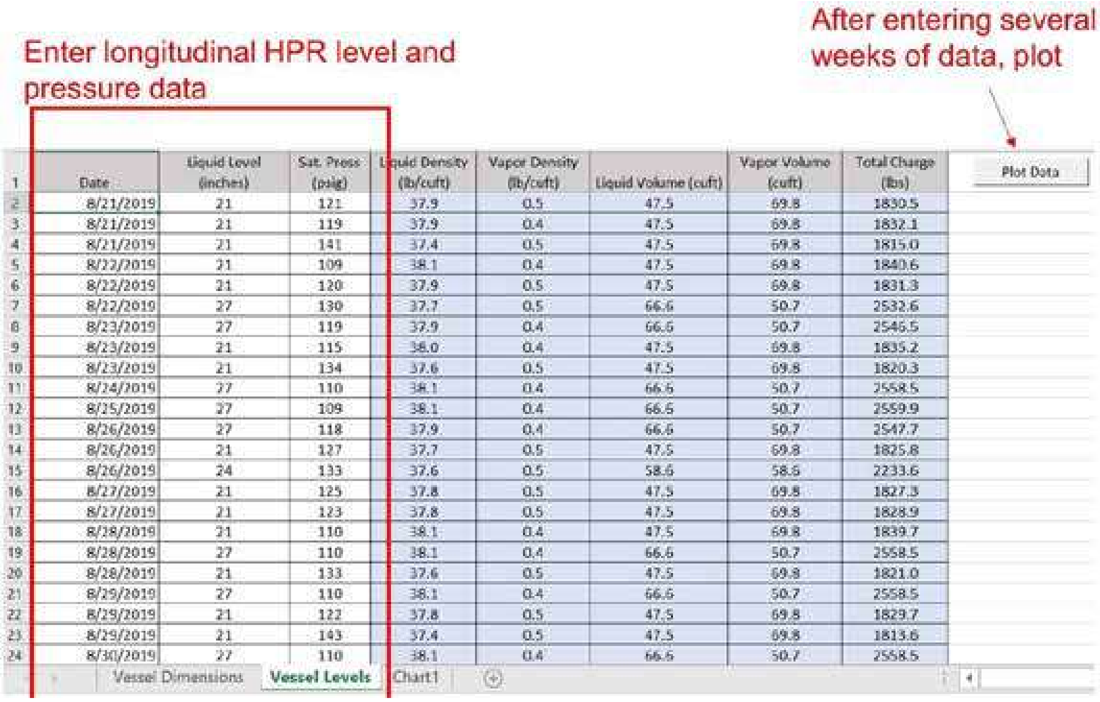
2) In the "Vessel Levels" tab enter the *date* of the reading, the *vessel liquid level (inches)*, and either the *saturation pressure* or *temperature* at the time the level reading was taken. Cell "C1" has a drop down to select temperature or pressure for the conditions column. The refrigerant charge of the vessel is then calculated by the tool.
Possible errors to be aware of are: entering a liquid level greater than the maximum possible, entering an invalid date, or entering a saturation condition outside of the table in columns "J"-"M". Dates must begin in row 2.

effective as well.

Set-up is available when the "Vessel Dimension" tab is selected.

4) Us Levels" cell "I1" to generate a graph of the vessel charge over time with a trendline to

Figure 10. Initial setup of the dynamic inventory tracking requires entering the HPR orientation and dimensions in the "Vessel Dimensions" tab of the spreadsheet.


Enter longitudinal HPR level and pressure data

After entering several weeks of data, plot

1	Date	Liquid Level (inches)	Sat. Press (psig)	Liquid Density (lb/cuft)	Vapor Density (lb/cuft)	Liquid Volume (cuft)	Vapor Volume (cuft)	Total Charge (lbs)
2	8/21/2019	21	121	37.9	0.5	47.5	69.8	1830.5
3	8/21/2019	21	119	37.9	0.4	47.5	69.8	1832.1
4	8/21/2019	21	141	37.4	0.5	47.5	69.8	1815.0
5	8/22/2019	21	109	38.1	0.4	47.5	69.8	1840.6
6	8/22/2019	21	120	37.9	0.5	47.5	69.8	1831.3
7	8/22/2019	27	130	37.7	0.5	66.6	50.7	2532.6
8	8/23/2019	27	119	37.9	0.4	66.6	50.7	2546.5
9	8/23/2019	21	115	38.0	0.4	47.5	69.8	1835.2
10	8/23/2019	21	134	37.6	0.5	47.5	69.8	1820.3
11	8/24/2019	27	110	38.1	0.4	66.6	50.7	2558.5
12	8/25/2019	27	109	38.1	0.4	66.6	50.7	2559.9
13	8/26/2019	27	118	37.9	0.4	66.6	50.7	2547.7
14	8/26/2019	21	127	37.7	0.5	47.5	69.8	1825.8
15	8/26/2019	24	133	37.6	0.5	58.6	58.6	2233.6
16	8/27/2019	21	125	37.8	0.5	47.5	69.8	1827.3
17	8/27/2019	21	123	37.8	0.5	47.5	69.8	1828.9
18	8/28/2019	21	110	38.1	0.4	47.5	69.8	1839.7
19	8/28/2019	27	110	38.1	0.4	66.6	50.7	2558.5
20	8/28/2019	21	133	37.6	0.5	47.5	69.8	1821.0
21	8/29/2019	27	110	38.1	0.4	66.6	50.7	2558.5
22	8/29/2019	21	122	37.8	0.5	47.5	69.8	1829.7
23	8/29/2019	21	143	37.4	0.5	47.5	69.8	1813.6
24	8/30/2019	27	110	38.1	0.4	66.6	50.7	2558.5

Figure 11. Example of information taken from the Dynamic Vessel Inventory Tracking tool.

When several days or weeks or months of data have been collected, the user can click on the “Plot Data” button and the tool will automatically generate a plot that includes each of the entries as individual data points as well as a linear trendline applied to the entered data, as shown in Figure 12. The tool uses the trendline to estimate the annual average refrigerant loss rate (lb_m/yr) as well as a curve fit to the trendline that includes an estimated daily loss rate based on the slope of the trendline (for the case shown in Figure 12, the daily loss rate is 3.1 lb_m/day [1.4 kg/day]). Users of the tool should carefully inspect the plot of data points and identify if there are any outlier points that may be reflective of a data entry error. If errors are found, the user can make corrections to the corresponding data in the “Vessel Levels” tab and replot.

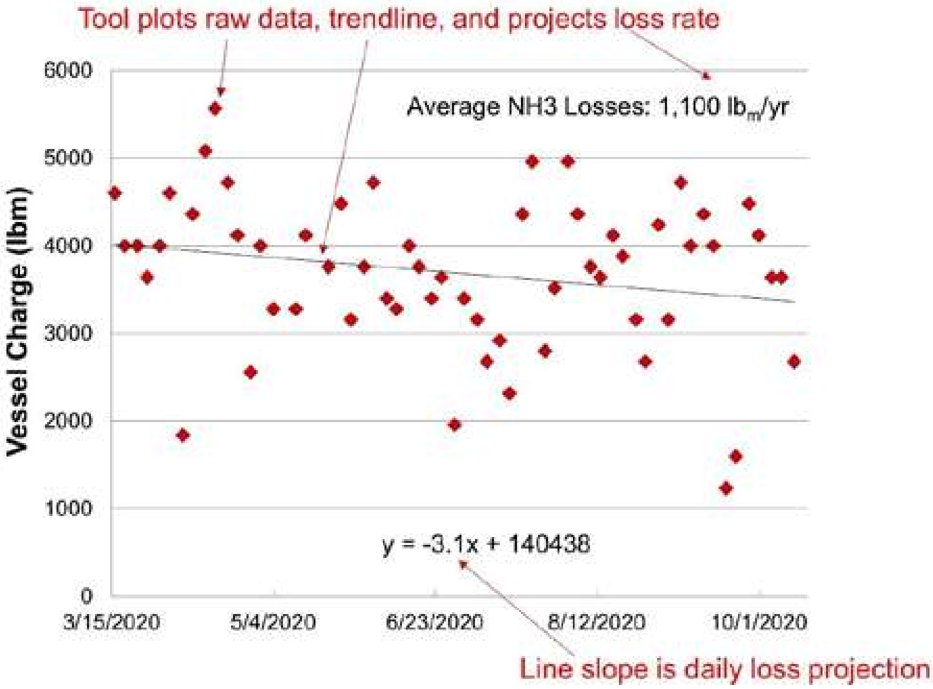


Figure 12. Plot of dynamic inventory tracking data showing a downtrend in vessel level totaling an estimated loss rate of 1,100 lb_m/yr [499 kg/yr].

The number of data points required to provide a reliable estimate of ammonia losses varies from system to system and can also vary throughout the year. There are times, for example during the fall season as system loads lessen, when the HPR may show an apparent accumulation of refrigerant inventory. Conversely, other times of year may show a much steeper downward trend as loads become more active.

Additional data logged into the tool will help smooth out the various factors that may confound or mask refrigerant losses that are actually occurring. This dynamic inventory calculator is not intended to be the decisive measure of refrigerant losses. It is best used as a guide to accompany other activities meant to reduce refrigerant losses and alert refrigeration personnel to investigate potential refrigerant losses more closely if the downward trend in refrigerant accelerates over time.

It’s important to be cognizant as to how modifications will impact refrigerant inventory in a system as equipment is added or removed. When these changes occur, they not only alter the distribution of refrigerant within the system, but they also alter the trendline of uncontrolled level vessel charge as well. When making system modifications, it is recommended that the plant create a new, separate dataset, and restart the trending process.

Systems that experience significant seasonal or other operational variations may have other options to track refrigerant inventory over time. For a system that is routinely shut down, vessel levels could be taken during shut-down times, thereby eliminating fluctuations from loads.

Conclusion

Fugitive emissions of ammonia to air from industrial refrigeration do occur, but they do not rise to the level of being principally responsible for the refrigerant losses these systems experience over time. Accidental releases and venting of refrigerant during maintenance activities are the two categories more likely responsible for nearly all refrigerant loss during a system’s operating lifetime. Reducing the frequency and severity of accidental releases can be accomplished by developing and implementing sound mechanical integrity programs that regularly inspect and test components. When accidental releases do occur, plants must develop estimates of the quantity of ammonia released during the event and then maintain a running total of the release quantity for reconciling with future system top-offs. Determining the quantity of refrigerant accidentally released can be challenging, but Reindl and Jekel (2016) provide guidance for preparing estimates of refrigerant release quantity associated with incidents and accidents.

Process owners can also take steps to reduce refrigerant losses associated with maintenance activities by recovering and reusing ammonia rather than simply venting the refrigerant to atmosphere or absorbing the ammonia in a water tote for later treatment or disposal. Some plants are equipped with specialized "pump-out systems" where the refrigerant can easily be evacuated from a portion of the system in preparation for maintenance. Most plants do not have dedicated pump-out systems, but those facilities should be capable of making temporary connections to transfer refrigerant from a portion of the system planned for service. This avoids discharging larger quantities of ammonia from the system. The method of dynamic charge calculation introduced in this paper provides a means for plants to identify and estimate a system's refrigerant loss rate to trigger active leak identification and repair.

As a target, we propose an annual refrigerant loss rate of the lesser of 5%/yr or 2,000 lb_m/yr as a threshold for unaccounted refrigerant losses that would prompt an investigation to find and repair a leak. The 5%/yr loss rate threshold is both attainable and reasonable for small-to-moderate size industrial refrigeration systems. For large systems, a fixed loss percentage can translate to significant quantities of ammonia that should not escape the attention of a plant. In this case, the 2,000 lb_m/yr benchmark would be applied as a threshold to trigger an investigation for leaks and initiation of repair as needed.

References

Commission for Instruments and Methods of Observation. CIMO Expert Team on Standardization, Pressure Reduction Formula. Geneva, Switzerland: World Meteorological Organization, November (2012).

EPA, "Risk Management Plan Program," data derived from RMP submissions analyzed in April (2020).

EPA, Office of Air Quality Planning and Standards, “Protocol for Equipment Leak Emission Estimates," Research Triangle Park, NC, U.S. Environmental Protection Agency, November (1995).

EPA, Air Emission Measurement Center (EMC), “Method 21 Determination of Volatile Organic Compound Leaks," https://www.epa.gov/emc/method-21-volatile-organic-compound-leaks, August 3 (2017).

IIAR 6, “Inspecting, Testing, and Maintenance of Safe Closed-Circuit Ammonia Refrigeration Systems," International Institute of Ammonia Refrigeration, Alexandria, VA (2019).

IIAR ARTG-GDL1, “Ammonia Refrigeration Training Guideline," International Institute of Ammonia Refrigeration, Alexandria, VA (2007).

IIAR 7, “Standard for Developing Operating Procedures for Closed-Circuit Ammonia Refrigeration Systems,” International Institute of Ammonia Refrigeration, Alexandria, VA (2019).

IRC, “Dynamic Charge Calculation Tool," Industrial Refrigeration Consortium at the University of Wisconsin-Madison, Madison, WI, https://irc.wisc.edu/file.php?ID=508, (2020a).

IRC, “Guidance Document – Best Practices for Calculating Refrigerant Inventory and Identifying and Reducing Fugitive Emissions," Industrial Refrigeration Consortium at the University of Wisconsin-Madison, Madison, WI, https://irc.wisc.edu/file.php?ID=510, (2020b).

Reindl DT, Denkmann JL. “Automatic Purgers in Refrigeration Systems," ASHRAE Journal, Vol. 43, No. 8, pp. 30-36, August (2001).

Reindl DT, Jekel TB. "Revisiting Refrigerant Release Estimates," IIAR Conference Proceedings, Orlando, FL, March (2016).

Reindl DT. Principles and Practices of Mechanical Integrity Guidebook for Industrial Refrigeration Systems, University of Wisconsin-Madison, Industrial Refrigeration Consortium, ISBN: ISBN: 978-0-0074258-0-2, (2016).

Reindl D, Claas M, Davis J, Grayless J. "Reduction of Fugitive Emissions from Industrial Ammonia Refrigeration Systems" Final Report. EPA Grant Number: 00E02366, (2020a).

Section 608, Clean Air Act and EPA regulations for protection of stratospheric ozone 40 CFR Part 82, Subpart F) prohibit venting of ozone depleting refrigerants (Class I and Class II).

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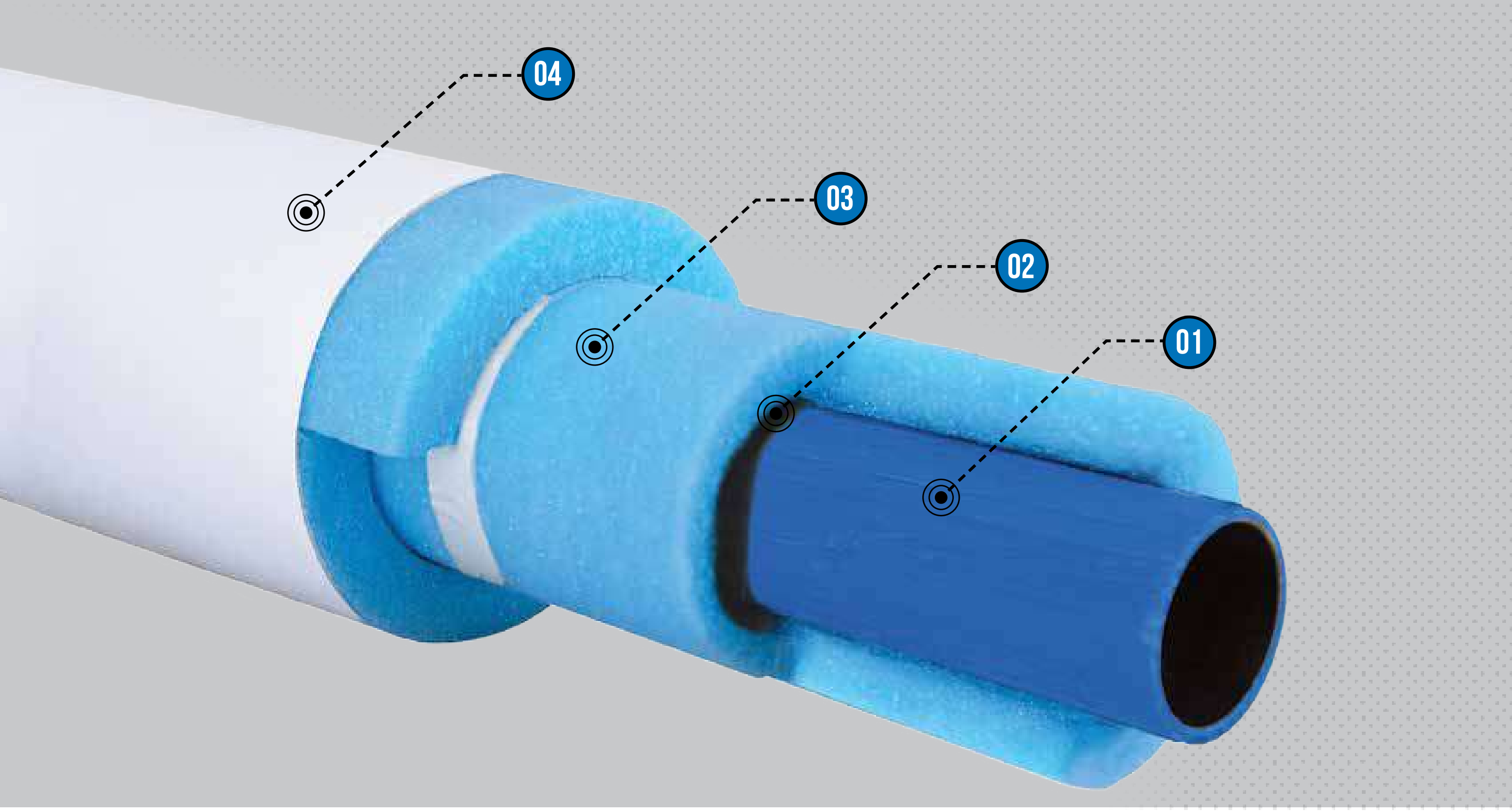

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