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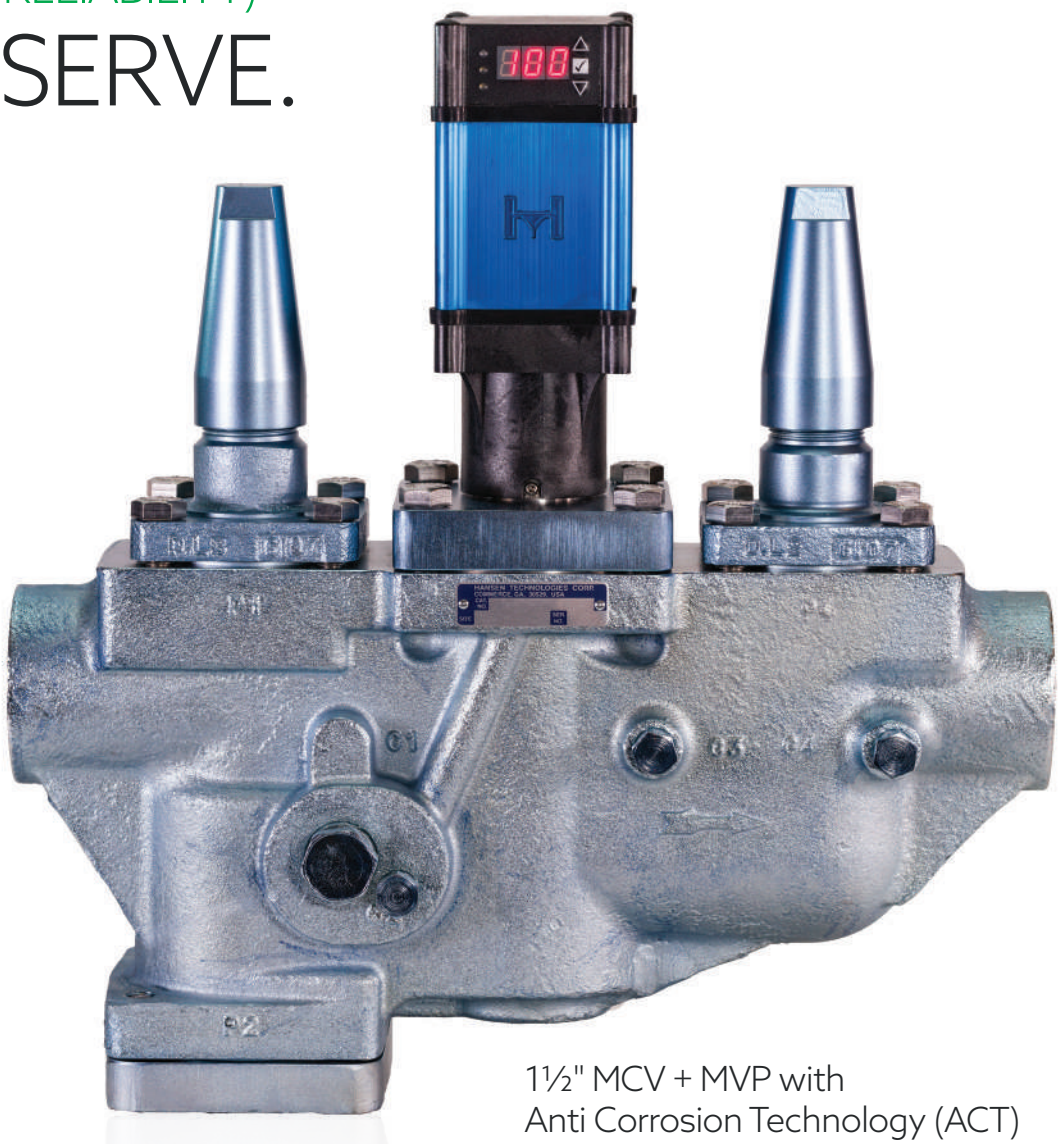

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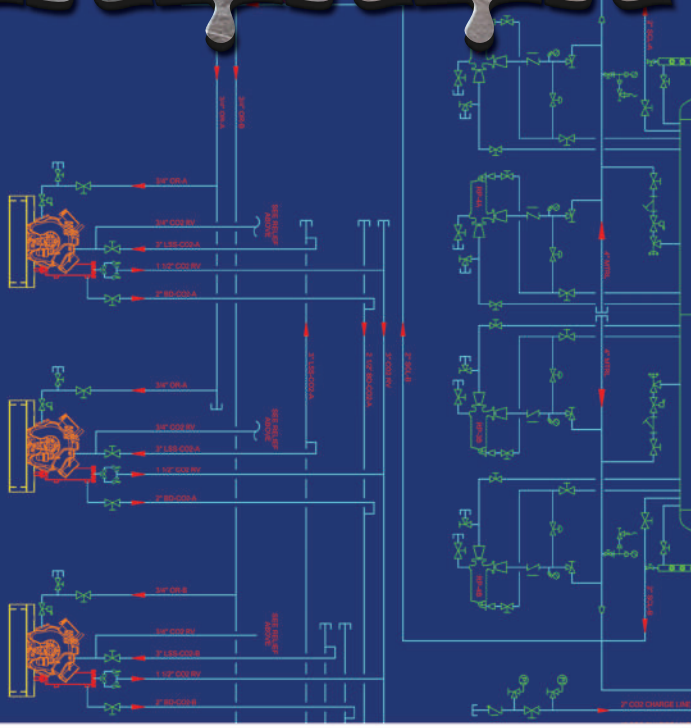

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IIAR Launches Apprenticeship Program

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COVER STORY
Apprenticeship programs help businesses develop highly-skilled employees, reduce turnover rates, increase productivity and lower the cost of recruitment. They can also help employers attract new employees, and IIAR along with its partners have created an apprenticeship program for refrigeration mechanics/technicians that can help boost the overall workforce within the refrigeration industry.

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president's MESSAGE

BY DAVE RULE

This issue of the Condenser is all about education and training. As you can see from our cover, IIAR is unveiling a new apprenticeship program which will help our industry safeguard the generations of institutional knowledge we rely on for the development of our future technicians, engineers and managers.

Alongside apprenticeship, we're continuing the focus on education that began earlier this year with the launch of IIAR's first certificate program. This was a major initiative for us: to broaden the reach of our member base by addressing changes that are occurring in our industry and promote the ongoing growth and health of industrial refrigeration.

Preparing the next generation is a central goal of any education program, and strengthening the knowledge, technical resources and leadership available to everyone in our industry right now is the first step.

Whether those resources inform regulators or help seasoned managers increase safety, our new emphasis on education is critical in answering and addressing the challenges we face.

I'm focusing my column this month on IIAR's Academy of Natural Refrigerants because I want to remind everyone – whether you're just learning about natural refrigerants or have been working with them for decades – that continuing your education is the single most important thing you can do to improve safety in our industry, and support IIAR and your fellow professionals.

Our Academy of Natural Refrigerants began with an initial IIAR-2 class which was unveiled at the last annual conference. That was followed with a round of new classes that are now available online for members to complete their IIAR-2 course work remotely.

Last month, we carried forward the IIAR-2 classes and exams and released similar classes and exams for IIAR Standards 4, 5, and 8. Next up is an introduction course for Process Safety Management and Risk Management slated for release in January.

The PSM and RMP module will be the first of several PSM/RMP course modules that will be offered by both IIAR and the University of Wisconsin to provide a comprehensive certificate for PSM/RMP professionals working in our industry.

Our expansive program is being designed for the long term – to provide members with educational choices to meet their business and professional development requirements, and I hope you, as an IIAR member, will find value in it for years to come.

To help our industry address regulatory requirements for safety training and increase a general understanding of good engineering practices, we need more than basic education. So, I'm happy to announce that IIAR is expanding the Academy of Natural Refrigerants to provide that comprehensive engineering training that will allow everyone in our industry to build professional credentials.

In January, we'll introduce a formal pathway to professional credentialing. The new designation, the "academy of natural refrigerants specialist," or ANRS, will serve as a comprehensive credential for the natural refrigerants industry.

The ANRS designation can be obtained through three different course tracks, and IIAR members will be able to choose their track to earn a comprehensive specialist's certificate.

The three certificate tracks designed for engineers and regulatory personnel working in our industry are focused on: the IIAR suite of safety standards; process safety (a PSM coordinator track and a PSM auditor track); and basic engineering. To earn the ANRS Certificate, students will be required to complete designated courses in all three tracks within five years of beginning the program.

The ANRS Certificate program will follow the guidelines established for ANSI certificate programs and become a primary method for industry professionals and regulatory personnel to expand their knowledge and build their professional credentials in the natural refrigerant industry.

IIAR's ANRS Certificate is just the latest step in your organization's ongoing work to make our industry the safest and most efficient it can be. As a group, education is one of the best ways to share our passion and dedication for what we do.

I'll end this month's column with a challenge to IIAR members and nonmembers alike. This year, become your industry's best advocate by taking an active role in your continuing education and join us in Colorado Springs, March 18-21, 2018 for what promises to be the best natural refrigerants conference and expo this year. Get involved in the work of the IIAR committees and lend your voice and experience to one of our many member projects.

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chairman's MESSAGE

WALTER TEETER

We're only three months away from the 2018 IIAR conference, and your staff at headquarters is working hard to wrap up annual conference programming for an event that promises to be one of the most exciting IIAR meetings yet.

We're back at the always popular Broadmoor Hotel in Colorado Springs, CO next March (18 – 21), and I'm happy to report that it's already shaping up to be another record breaking year.

As always, we will be bringing you all the latest information on the newest technologies and trends that are shaping our industry, with a special focus on the new opportunities for ammonia and other natural refrigerants in markets where synthetics have been traditionally dominant.

If you want to stay updated and knowledgeable about the latest advancements in industrial refrigeration, the IIAR annual conference truly is a must-attend event.

We're expanding our technical program this year to include more Tech Paper sessions, Workshops and Panels designed to address growing opportunities for natural refrigerants in both the industrial and commercial market sectors.

But the most anticipated conference event is our Monday night reception, which will be held at the U.S. Olympic Training Center.

The Monday night gathering is always a great opportunity to socialize and catch up, but this year it's special because we'll all have the chance to tour our nation's Olympic training facility to see firsthand how and where athletes train.

Anyone who attends will also get to watch Olympic athletes giving exhibitions in their sport and get a chance to take a shot on the target shooting range.

This is a once in a lifetime opportunity and a first for IIAR. Join us for the networking and fun, and stay for the lessons in preparedness. Your tour of the training center will reveal firsthand the importance of training for your own environment and staying prepared – whether it's for an emergency event, or just an everyday problem.

That's a theme we'll continue back at the Broadmoor, where safety will take a prominent spot in our conference program.

Conference highlights this year include peer-reviewed technical papers, experimental workshops and engaging panels on topics including emergency response in an ammonia refrigeration facility, hot gas defrost, use of water as a refrigerant, and stainless-steel piping in industrial refrigeration.

Exclusive to the 2018 IIAR Conference is the Sunday afternoon Mechanical Integrity for Ammonia Refrigeration Systems Education Program. This education program provides a comprehensive outline of compliance regarding mechanical integrity for ammonia refrigeration systems with information on the basic components of a mechanical integrity program, minimum requirements of inspection, testing and maintenance as well as preventative maintenance, audits, training and quality assurance.

And as always, The IIAR Expo hall will highlight the latest designs in cutting-edge commercial and industrial refrigeration equipment. With more than 150 exhibitors in attendance, the exhibition hall hosts product displays from the industry's leading manufacturers and service providers.

One of the most important functions of our annual conference is to provide a place for our committees to review their work, set new yearly goals and welcome new IIAR member volunteers.

As we close out 2017 and look forward to a new cycle of growth for our organization, I'd like to encourage you to explore our committee work and get involved. The projects our committees complete – from standards creation to safety guidelines to education initiatives are all the basic, vital activities that make a real difference in our regulatory and operating environment.

Whether it's testing new technology or new practices, increasing communication with regulatory agencies or developing cutting edge resources like standards and safety training, we can't do any of it without you.

Our committees move our ideas and initiatives from abstract goals into reality. And at the same time, our officers, volunteer and voting members bring so much of their own knowledge and experience to our organization as they direct the goals of the IIAR committees.

If you are an IIAR member and have not yet had a chance to get involved in the work of your industry, I urge you to take a look at how your expertise might help an IIAR committee further its work goals.

I'd also like to extend a special thank you – to our sponsors for their support, and to you, our members, for the incredible engagement and dedication that you bring to this organization. I look forward to seeing you in Colorado Springs in March!

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IIAR Launches Apprenticeship Program

BY MINDY LONG

Apprenticeship programs help businesses develop highly-skilled employees, reduce turnover, increase productivity and cut the cost of recruitment. They can also help employers attract new employees.

To realize these benefits, the International Institute of Ammonia Refrigeration, in partnership with other organizations, has created an apprenticeship program for refrigeration mechanics/technicians that can help boost the overall workforce within the refrigeration industry.

"The Foundation was pleased to take the lead in this important mission. There are over 40,000 jobs waiting to be filled nationally. Earning While You Learn, is a great way to build America's workforce, and support the growing needs of our industry as a whole," said Foundation Executive Director Lois Stirewalt O'Connor.

IIAR worked with the Ammonia Refrigeration Foundation, Refrigerating Engineers Technicians Association, Global Cold Chain Alliance, Lanier Technical College-Technical College System of Georgia and Fastport Inc. to develop the program, which is designed to train an ammonia gas refrigerant technician in all phases of the industry. It combines well-developed on-the-job learning combined with related instruction.

Dave Harrison, executive director, national apprenticeship for Fastport, said it is easy for employers to participate in the apprenticeship program. "The major paperwork element has been taken care of already. All you have to do to have a registered apprenticeship program is to fill out and sign the employer acceptance agreement saying you are going to participate in the apprenticeship in a fair and equitable manner," he said.

Employers need to submit the individual training processes they use to bring an employee from the point of hiring to a journeyman or to turn-key status for their company's needs. There is no one-size-fits-all approach or specific training program that an individual employer must follow, althoughthere are minimum standards that must be met (see sidebar on next page). Harrison said that the process is designed for an employer to do what they are going to do already but as part of a formalized process.

"They submit their training plan in a simple, outlined format," Harrison said. "While the certifications are universal, each employer has its own idiosyncrasies and may even have separate idiosyncrasies by location."

There is no cost to IIAR members for the program and it isn't time consuming. "It only requires you to process one piece of paper for every person that goes into the program. Literally that is all that is required to enter an apprenticeship program," Harrison said, adding that it takes less than five minutes.

According to the U.S. Department of Labor, every registered apprenticeship program must have a sponsor that is responsible for the overall operation of the program. "Sponsors can be a single business or a consortium of businesses. They can also be a range of workforce intermediaries, including an industry association or a joint labor-management organization," DOL said.

The apprenticeship program doesn't mandate a specific number of participants per employer. "There is no quota. In fact, just because you have an apprenticeship program doesn't mean you have to use it. You can establish it and have it ready for when you want to use it," Harrison said.

Once the apprentice has completed all of the requirements of the apprenticeship program, the sponsor will certify the information and request a Certificate of Completion of Apprenticeship.

POTENTIAL FINANCIAL BENEFITS

One of the biggest benefits to employers is improved retention. More than 90 percent of apprentices that complete an apprenticeship are still employed nine months later, DOL reported.

In addition to the retention benefits, there can be potential financial benefits to employees taking part in apprenticeship programs as well as for employers that implement them.

If employers engage veterans, any veteran who is eligible for the GI Bill

who is participating in the apprenticeship program can draw a monthly housing allowance, which averages about $1,400 a month. "It comes out of that individual's GI Bill. For those participants, retention is off the charts," Harrison said.

For the employee to get the GI Bill benefits, the employer has to certify the hours the apprentice works. It does require additional paperwork, but Harrison said it is worth it because of the increased retention levels.

The DOL said businesses sponsoring apprenticeship programs may qualify for state-based tax credits. "Workforce systems and other community partners may also choose to contribute funding for training, supplies or other aspects of apprenticeship programs," the agency said.

Last year more than $55 million went out in American Apprenticeship Initiative grants, and Congress approved $90 million for growing and expanding apprenticeship programs, Harrison said. "This year they approved $95 million," he said, adding that President Donald Trump issued an executive order to shred the paperwork and regulatory burden.

While there is specific funding earmarked by the government at all levels for the purposes of advancing or expanding apprenticeships, how much is available to individual employers can vary by geographic location.

AN INCREASED FOCUS ON TRAINING

The Labor Department's National Office of Apprenticeship has set a goal of doubling and diversifying the number of apprenticeships by 2019. During a hearing on Capitol Hill in November, Labor Secretary Alexander Acosta said it is critically important to change the perception that college is the only pathway to a productive lifelong career.

"This is an issue that is so important. We should be growing apprenticeships in this nation," Acosta said, adding that people should be encouraged to pursue job training that matches their interests and talents.

Several states are encouraging programs as well. In Kansas, Mike Beene, the executive director of Department of Commerce workforce services, said apprenticeship programs need to be expanded. "If a person can learn a craft or a skill or even competencies associated with a job, and have that model of earning a paycheck while you're learning, I just think it makes sense for Kansas businesses as a way to attract and grow talent," he said.

THE ROLE OF APPRENTICESHIPS

Registered apprenticeship training is distinguished from other types of workplace training by several factors. The participants can be either newly hired or already employed and must earn wages from employers during training, the DOL said. Programs must meet national DOL standards and provide on-the-job learning and job-related technical instruction.

Several industries have proven the success of apprenticeships. The DOL reported that registered apprenticeship programs offer access to 1,000 career areas, including software developers, engineers, pharmacy technicians, telecommunications technicians, aircraft technicians, mechanics, welders, insurance agents and truck drivers.

"Over 150,000 businesses have adopted Registered Apprenticeship, including UPS, Ford Motor Company, the United States Military, Werner Enterprises, CVS/Caremark Pharmacy and many others," the DOL reported.

The AFL-CIO partners with several industries, including health care, construction, manufacturing, hospitality and aerospace, to promote apprenticeships. The programs benefit employers as well as the country, AFL-CIO said, noting that joint labor-management training programs in the building and construction industry contribute about $1.5 billion to the American economy every year.

ATTRACTING EMPLOYEES, APPRENTICES

Harrison said there are numerous ways of attracting apprentices. "One is to develop a successful military engagement program that interfaces with organizations, like Fastport and others, in order to find candidates."

Other approaches include using workforce centers and word of mouth. "This happens quite often on apprenticeships because you have specialized skills," Harrison said.

IIAR members interested in implementing an apprenticeship program can contact Harrison at (479) 231-9666 or dave.harrison@fastport.com for guidance.

Minimum Instruction Requirements

The apprenticeship program has minimum instruction requirements, which are outlined within Appendix A of the program. This instruction shall include, but not be limited to:

Class	Contact Hours
Industrial Ammonia Refrigeration Level I	40
Industrial Ammonia Refrigeration Level II	40
Maintenance and Trouble Shooting for the NH3 Operator	40
Math for the Ammonia Technician	24
	Sub-Total: 144
PSM/RPM for the Ammonia Operator	40
Industrial Ammonia Refrigeration Level III	40
RETA Basic Electricity I	40
24-Hour HazMat Technician Certification	24
	Sub-Total: 144
RETA Basic Electricity II	40
RETA Control Theory I	40
Introduction to Industrial Maintenance	40
PLC Maintenance & Trouble Shooting	24
	Sub-Total: 144
	Grand Total: 432

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Cold Chain Plays a Crucial Role in Emergency Preparedness

Disaster takes many forms – just this year, various sections of the U.S. have experienced catastrophic hurricanes, wildfires and flooding, all of which can knock out – sometimes for a long time – utilities that are essential to maintaining business. Earthquakes, tornados and blizzards are other major threats.

For food manufacturers, wholesalers and supermarkets and others that rely on electricity or that can be damaged by storm or other events, disaster preparedness is an essential business practice.

"We're constantly thinking about resiliency and business continuity. Whether it is a storm, a prolonged power outage because of rolling blackouts or catastrophic events like the wildfires we've experienced in California," said Tristam Coffin, director of sustainability and facilities for Whole Foods Market.

Whole Foods has partnerships with generator suppliers/disaster relief contractors and owns mobile generators it can deploy to affected stores to provide enough energy to operate refrigeration systems, and the grocer has recently tested Axiom Exergy's Refrigeration Battery solution at its store in Los Altos, California, which could eventually allow it to keep food cold by relying on thermal storage.

"Supermarkets by their very nature have an important role in helping with emergencies when they happen. They have a lot to think about ahead of time, so that they are able to respond when their communities need them most," said Keilly Witman, owner of KW Refrigerant Management Strategy.

H-E-B, a grocer with a significant presence in Texas, has mobile kitchens, a Disaster Relief Unit and two water tankers that it can deploy to areas hit by a natural disaster. The grocery also employs a full-time director of emergency preparedness and constantly monitors weather patterns.

Justen Noakes, director of emergency preparedness at H-E-B, told Texas Monthly the company was watching Hurricane Harvey a week before it formed and activated its emergency process before the storm made landfall, devastating much of the Houston region. The company was prepared for a significant impact. H-E-B activated its mobile kitchens and disaster response unit, which includes a mobile pharmacy and a business center.

H-E-B also works to open its stores quickly after a disaster. "A lot of the time when we roll up to these stores after a disaster, we'll have customers waiting out in front of our stores waiting for us to open," Noakes said in a Q&A with the magazine.

Peter Jordan, senior principle engineer with MBD Risk Management Services, Inc., based in Langhorne, Pennsylvania, said the goal of any emergency preparedness plan is to anticipate problems that may occur and develop plans to limit their impact.

Emergency plans vary based on where you are in the country and store design takes that into consideration.

Coffin said Whole Foods stores in California are designed for seismic activity whereas stores in Florida are more concerned with hurricanes. "Emergency plans are similar but different in certain respects," he said.

"Certain types of emergency situations involve at least some advanced warning," Witman said. "Like a snow storm that drops four feet of snow or a hurricane that is forecast to hit a particular area. Those situations allow for a different level of preparedness than you'd have for tornadoes or earthquakes."

Jordan said in some areas, such as California, regulations require a seismic analysis to be done ahead of time. These analyses often require changes to the system including the installation of seismic bracing. However, he added that there are always disasters that operators can't anticipate. "I knew of a plant where they had a near miss occur when a process tank overflowed. The resulting internal flood almost caused a large ammonia release. Prior to this near miss, I hadn't anticipated this type of scenario. I now cover internal floods in all of my analyses," he said.

PLANNING AT INDUSTRIAL FACILITIES

Industrial plants also must address emergency planning. Many facilities incorporate this emergency planning into their written operating procedures. Jordan often develops system operating procedures that include steps to take if disasters such as power failures, fires, bomb threats or hurricanes were to occur.

Campbell Soup Co. has emergency action plans for each of its facilities, which can also vary by location. "Our facility in Florida has hurricane evacuation plans. In Texas, we have tornado shelter-in-place plans in place," said Bing Cheng, manager of utilities engineering at Campbell's.

As part of its evacuation plans, Campbell's has established meeting points for employees and identified coordinators that take attendance to make sure everyone has left the building. Campbell's also has an action plan for an active-shooter situation for all its facilities.

For Campbell facilities that utilize ammonia, there are emergency action plans specifically for ammonia systems. "We have detailed emergency procedures in the event of an ammonia release or power outage. As part of our employee and operator training, we review our evacuation plans in case of any releases that may occur," Cheng said.

When Hurricane Harvey threatened, the Campbell's facility in Lakeland, Florida, was closed during the storm as a precaution. The engine room was in the process of being commissioned, so employees made sure all equipment was secured and all the contractors were taken off site, Cheng said.

To help minimize product loss, Campbell's can shift production runs if there

is advanced notice. "If you have a sudden storm or a tornado, that can cause issues with production," Cheng said.

Campbell's also relies on diesel-powered equipment for back up. "Most of our fire protection pumps have a diesel-powered pump backup," Cheng said. "If we do lose power to our ammonia refrigeration system, our operators are trained to get the system stabilized and back online as quickly and safely as possible to minimize production downtime."

Like Whole Foods' Coffin, Cheng is looking into battery solutions. "With improvements in batteries and the size we need, it is feasible now," he said. "It protects you during some outages and it takes some of that peak demand out of your utility bills."

Depending on the nature of the emergency, a pump-out procedure could improve safety. "What you do is slowly shut down the plant, stopping the flow of ammonia to the system evaporators and allow it to be drawn back to engine room vessels — typically a high-pressure receiver — and wait it out," Jordan said.

The length of time it takes to pump out ammonia varies, depending on the size of the systems. A very small ammonia refrigeration system can be pumped out in one or two hours. Larger facilities may need a day or more to complete the process. "You need to prepare. You can't just decide to do it moments before a storm hits," Jordan said.

If a fire is approaching a facility with ammonia, the primary question is whether or not to pump out and shut down the ammonia refrigeration system. "Most of the plants I'm familiar with have shut down their systems when a fire was approaching, but I know of at least one example where the facility did not shut down the system without suffering any major consequences," Jordan said.

In addition to protecting the companies' brands and meeting consumers' and communities' needs, operators' emergency preparedness plans can help them meet regulatory requirements. When a hurricane is approaching, the Environmental Protection Administration will often send out alerts asking companies if they have thought through their hurricane plan. "Blaming an ammonia release on an 'act of nature' may not be an acceptable explanation to a regulator. Regulators expect facilities to be prepared, so don't be caught short," Jordan said.

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The Future of Natural Refrigeration Begins Here

40th Annual Meeting
March 18 – 21, 2018
Colorado Springs, Colorado

The future of industrial refrigeration begins at the 2018 Natural Refrigeration Conference & Expo. This annual event will take place March 18-21 at the Broadmoor Hotel in Colorado Springs, CO.

Showcasing the latest equipment, products, services and technologies available in natural refrigeration, this tradeshow provides attendees the opportunity to meet with over 1900 industry professionals, reconnect with clients and network with industrial refrigeration experts and key decision makers from around the world.

The show will kick off with motivational keynote speaker, Vince Poscente, who went from civilian to Olympian in only four years. Poscente competed for Gold at the Olympic Winter Games in Albertville, France, blasting down the mountain at an incredible 135 mph on skis. With his unique experience in training for the Olympics, he has become an internationally sought after expert on goal acceleration.

The popular Monday night networking event will be held at the Olympic Training Center in Colorado Springs, CO. The U.S. Olympic Complex in Colorado Springs is the proud flagship training center for the U.S. Olympic Committee and the Olympic Training Center programs. It is the year-round home to athletes and coaches as they train for the next Olympic Games. As part of the IIAR event, athletes will guide attendees through the facility and describe how they are preparing for the Olympics. There will be athletic demonstrations including jousting, boxing, gymnastics and Olympic shooting. There will even be the potential for interactive fun at the shooting range.

Conference highlights include a 2.5-day technical program consisting of peer-reviewed technical papers, experimental workshops and engaging panels on topics including emergency response in an ammonia refrigeration facility, hot gas defrost, use of water as a refrigerant, and stainless-steel piping in industrial refrigeration.

The IIAR Expo hall unveils the latest designs in cutting-edge commercial and industrial refrigeration equipment. With more than 150 exhibitors in attendance, the exhibition hall will host product displays from the industry's leading manufacturers and service providers.

Exclusive to the 2018 IIAR Conference is the Sunday afternoon Mechanical Integrity for Ammonia Refrigeration Systems Education Program. This education program provides a comprehensive outline of compliance regarding mechanical integrity for ammonia refrigeration systems with information on the basic components of a mechanical integrity program, minimum requirements of inspection, testing and maintenance as well as preventative maintenance, audits, training and quality assurance.

Attendees can also sit in a special Closing Forum highlighting the advancement of small charge ammonia systems through codes, regulations, and insurance.

In addition to the conference events, attendees will also be able to sit for certificate program testing at the meeting. The IIAR Academy of Natural Refrigerants Certificate Program is meant to help refrigeration professionals expand their knowledge base and develop their career credentials. Two certificate programs are currently available for testing, the IIAR 2 Certificate Course and the IIAR 4,5 and 8 Certificate Course.

The future of natural refrigeration begins here. To register to attend or exhibit or to learn more about the show, go to www.iiar.org.

2018 NATURAL REFRIGERATION CONFERENCE & EXPO

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Mechanical Integrity for Ammonia Refrigeration Systems
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This Education program highlights the importance of mechanical integrity, how it relates to process safety management and the General Duty Clause. Topics include:

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MEET OUR KEYNOTE SPEAKER

Vince Poscente is a former Olympian and motivational keynote speaker. He thrives on challenges, particularly those that help clients overcome adversity and sustain resiliency.

Vince began his Olympic career as Executive Director of the Alberta Luge Association and liaison with the host broadcaster for the 1988 Olympic Winter Games. Then he decided he wanted to be an Olympian. ***Vince went from recreational skier to the Olympics in four years.*** He became a five-time Canadian record holder, ranked 10th in the world and into the Speed Skiing gold medal round of the Olympic Winter Games in Albertville, France. Vince placed 15th skiing at a national record of 135 mph.

Vince has since become a New York Times bestselling author (writing seven books to date), inductee into the Speaker Halls of Fame (in Canada and the USA), a Masters of Arts in Organizational Management and adventurer leading and climbing in the Himalayas. He is the founder of the Heroes Climb initiative (climbing and naming mountains after every day heroes).

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Ammonia Holds Promise for Supermarkets

Natural refrigerants have the potential to provide supermarkets with methods to address environmental and regulatory changes, take advantage of long-term efficiency savings and reduce energy costs. Educating grocers about the benefits of the technology could contribute to increased demand. There are new opportunities within the industry as stores look for alternative ways to power refrigeration.

"With regulations changing right now and phase outs of HFCs, the end user is confused on what direction to take," said Randy Fernandez, zone manager-West Region, for Kysor/Warren. "We as a collective can do a better job to promote ammonia as a viable and efficient solution to the industry."

AMMONIA INSTALLATIONS

Supermarkets are investing in natural refrigerant technology, and Fernandez said those could increase as end users' comfort levels with ammonia rise.

In 2015, Piggly Wiggly installed an ammonia CO_2-cascade system from Kysor/Warren, and everything has been very positive, Fernandez said. "The installation process was extremely comparable to any other rack system that was previously installed by Piggly Wiggly," he explained.

Keith Milligan, chief information officer of JTM Corp., Piggly Wiggly's parent company, has said the system is using 30 percent less energy than a comparable store that uses the older technology. He has also said the system is as easy to maintain as others the company has in operation.

Fernandez said a key lesson learned from the installation was that Kysor/Warren could put together a customizable installation program that could be easily installed and supported. "There tends to be a lot of turnover with installers/field technicians. You can't just train them once and run for the hills. There has to be someone knowledgeable to take care of the store," Fernandez said, adding that Kysor/Warren provides on-site training.

For Milligan, the biggest benefits have been the energy savings and the fact that the company doesn't have to worry about a refrigerant change.

In addition to gaining efficiencies and having future-proof solutions, a move to natural refrigerants can also show consumers supermarkets are committed to the environment. "I only think it is going to continue as more and more consumers are educated on the benefits of natural refrigerants. I think there will be a level of expectation of supermarkets to join this effort and support the environment," Fernandez said.

AMMONIA MYTHS

Both Keilly Witman, owner of KW Refrigerant Management Strategy, and Fernandez said there are myths surrounding ammonia use in supermarkets.

"The ammonia systems for supermarkets have gotten the reputation that they are going to be about 100 percent more expensive than other types of systems, and that is a myth that started with that first ammonia/CO_2 cascade system in Carpinteria, California," Witman said. She added that the high cost of the Carpinteria store was because Albertsons had to buy an industrial ammonia system and buy a separate commercial CO_2 system, then pay an engineering firm to figure out how to make the two systems work together.

Ammonia systems that have been manufactured specifically for a commercial setting are more cost effective, Witman said, "though supermarket end users should still expect a cost premium until the technology is widespread enough for manufacturers to achieve economies of scale."

Witman said there is also a misperception in the commercial setting that installing an ammonia system in a supermarket will require two sets of contractors — one for the commercial side and one for the ammonia side. "That's just false. There are plenty of commercial refrigeration contractors that have technicians who are trained to operate and maintain ammonia systems."

Rebranding commercial ammonia systems could help supermarket end users understand that ammonia use in a commercial setting has very little in common with the big industrial systems.

"There is so much that is different about the two, including how much ammonia is in the refrigeration systems. Commercial ammonia systems can be designed to use less than 100 pounds of ammonia for the entire store, and all of the ammonia is on the roof, so there is no reason for anyone to come in contact with the ammonia refrigerant other than the trained service technician," Witman said. "Yet when you say, 'ammonia system,' people assume you are talking about the same thing you find in industrial applications. One of the greatest things we could do for commercial ammonia systems is to come up with a different name for them."

Fernandez said rebranding ammonia for commercial use could help the supermarket industry correlate it with safety and efficiency. "In a grocery store, ammonia is staged outdoors. Ammonia from a leak perspective would be easily detectable and no one in the building would be exposed," he said.

Increased education will help eliminate the myths and increase demand. "There are so many cost benefits that ammonia can offer. I think we're doing a disservice to the industry by not arming supermarkets with the information they need to make good decisions," Fernandez said. "Platforms like the North American Sustainable Refrigeration Council [and IIAR] serve as good resources to get the word out."

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Observations on the Chemical Safety Board report on the Millard Accident

The analysis and recommendations expressed here have been developed by the IIAR Safety Committee working with IIAR staff.

INTRODUCTION

In August of 2010, an accident occurred at the Millard Refrigerated Serviced facility in Theodore, Alabama. Subsequent to the accident, the United States Chemical Safety and Hazard Investigation Board (CSB) investigated the accident and later issued a Safety Bulletin "Key Lessons for Preventing Hydraulic Shock in Industrial Refrigeration Systems", published in January 2015. A summary of the accident and causes can be found in reviewing the CSB safety bulletin No. 2010-13-A-AL. As a result of the analysis, the CSB safety bulletin recommends certain design and operation practices intended to prevent hydraulic shock, and lessen the consequences of a release should one occur.

While the IIAR does not question the findings of the investigation, the IIAR believes it would be helpful to explore some of the statements and recommendations within the safety bulletin. This response was assembled with the input of numerous industry professionals with a wide range of experience in industrial refrigeration installations, operations, maintenance, and troubleshooting. This document addresses each of topics of interest and is intended to provide the basis for meeting the intent of the CSB recommendations while using alternate methods.

While better engineering controls (i.e. the design of the system and its controls) might have prevented or limited the consequences of the release, IIAR believes that operator training, operational discipline regarding following established procedures, and management of change of existing engineering controls, are at least equally if not more important. The lessons learned from the incident should be universally considered, but IIAR cautions that there are many approaches to safe design that can be considered for refrigeration applications.

FREQUENCY OF HYDRAULIC SHOCK

In section 3," Hydraulic Shock", the CSB bulletin states that "…hydraulic shock events are typically the condensation-induced type and frequently occur in low-temperature ammonia systems." IIAR respectfully suggests that while hydraulic shock events have not been totally eliminated from the industry, their frequency has declined. Understanding of the causes and prevention of hydraulic shock has improved over the past three decades, and changes have been implemented by the industry. IIAR agrees that the industry should continue to disseminate knowledge and best practices regarding this issue. It is important that owners, operators, contractors, and other stakeholders be knowledgeable about the symptoms of hydraulic shock, and that investigation and corrective action be initiated when such symptoms are observed.

"LESSONS LEARNED"

Section 6, paragraph 1 of the CSB bulletin (on lessons learned) states that grouping multiple evaporators to a single set of control valves should be avoided, and is especially important for large capacity evaporators more than 20 tons. IIAR respectfully disagrees that it is unsafe to group multiple evaporators to a single control group if the control valve group and the operating controls are appropriately designed. An appropriately designed control group will safeguard against hydraulic shock events regardless of the volume of the heat exchangers connected to it. The value of 20 tons may have had validity years ago when systems tended to be simpler and smaller. Today, some individual coils could provide much more capacity than 20 tons and conversely, several evaporators grouped together might provide less capacity than 20 tons. Further, the rating of an evaporator is dependent upon many factors including room temperature, suction temperature, air flow, surface area, coil internal volume, moisture load and other factors. While limiting control groups to a single evaporator might seem to provide an abundance of caution, and may enhance the operation or controllability, the design of the control group is the crucial factor in preventing hydraulic shock events resulting from defrost operations. Prudence does dictate that the larger the coil volume on a single control valve group, the greater the importance of ensuring that all necessary steps are taken to prevent hydraulic shock, and the greater the importance of taking corrective action if any symptoms of hydraulic shock are observed.

It is notable that the CSB bulletin does not discuss the use of slow-opening valves. The use of slow-opening gas-powered suction valves has been widespread for many years. These valves incorporate the use of a compensating spring and a pilot gas orifice that slowly balances the pressure on either side of the valve when pilot gas pressure is removed. The valve will not open until the pressure is equalized. A loss of power during a defrost cycle would initiate the automatic equalization of the coil pressure to suction pressure. This is essentially a passive way to ensure that there will not be a sudden introduction of hot gas from a defrosting coil introduced into the system's suction piping.

Motorized control valves have become increasingly popular to smoothly control the flow of refrigerant. These valves can be programmed to open gradually, and can be made able to slowly close themselves in the event of a power outage. While the use of these valves does not necessarily guarantee that hydraulic shock will be prevented, they do provide a means of protection that are not mentioned in the safety bulletin. Using these types of valves greatly reduce the risk of hydraulic shock, and can provide safety measures that would enable a variety of safe designs.

The CSB safety bulletin makes several suggestions in paragraphs 2 through 4 that presume controls systems are computer or PLC based. The IIAR agrees that if these suggestions can be implemented, they would enhance safety and reduce the risk of hydraulic shock. But there are

many systems that use electro-mechanical control for some or all a system's functions that will not permit the programming features suggested. Electro-mechanical systems can and should be designed to achieve similar goals.

There are also several other methods of defrost risk mitigation:

Low charge (DX) evaporators. These pump out significantly quicker than liquid overfeed coils and the probability of residual cold liquid remaining in the evaporator coils following conclusion of the pump-out cycle is less than it is for liquid overfeed or gravity flooded evaporators.

Hot gas defrost by means of a defrost medium that is not the primary refrigerant. These types of defrost methods use a separate defrost circuit interlaced with the primary refrigerant circuit. The primary refrigerant suction line exiting the evaporator remains open during defrost thereby greatly reducing the probability of liquid hammer of any form.

Automatic ambient air defrost as practiced in alcove and penthouse evaporators in warm climates.

The safety bulletin correctly implies that an ammonia release should be isolated promptly. The bulletin goes on to say that if a release cannot be promptly isolated, then the emergency shut-down switch should be activated. IIAR agrees this should be the default response for most facilities. The IIAR respectfully suggests that while this may be appropriate for most facilities, there are some facilities that have detailed planning, personnel, and equipment in place to facilitate making this decision in real time, as conditions and the situation dictate. Compressors create desirable low pressures within the low-side of refrigeration systems. Continuing to operate a compressor if a release is discovered may help to reduce the amount of refrigerant released. Releases on the high-pressure system may benefit from shutting off compressors. Many facilities develop emergency plans and train their personnel on appropriate implementation of the plans. This might include release mitigation that involves isolation without shutting down the compressors or other valves that automatically close upon activation of the emergency shut-down switch. Facilities which elect to allow operators to make decisions in real time as to whether to shut down the system should clearly state in their emergency plans which scenarios require immediate shutdown if prompt isolation is not possible, and which scenarios allow an operator decision to continue to run while other actions are being taken to terminate the release. If in doubt, the best option is to shut down the system.

CONCLUSION

In conclusion, the CSB report and this IIAR review should be considered useful references to designers, owners, contractors, and other stakeholders. This review offers some alternate methods that IIAR believes meet the intent of recommendations in CSB Safety Bulletin No. 2010-13-A-AL. The analysis draws on a history of successful practices and technologies that are intended to reduce the risk of hydraulic shock and release mitigation, while maintaining the ability to design and use economical arrangements to safely control refrigerant flow and system control. As with any design, maintenance routine, or emergency plan, the methodologies should be thoroughly reviewed by the designers, owners, and operators of the systems. Training on system operation and function, as well as on the facility emergency plan, should be incorporated at all levels of management and staffing. This is likely the most important lesson to be derived from the observations of the Millard incident.

Whole Foods Tests Battery Storage to Reduce Energy Demands

On average, grocery stores use about three times more energy per square foot than average retail spaces, with much of the use going to refrigeration. To help cut energy costs, future-proof against volatile energy markets and increase resiliency, Whole Foods Market is testing a Refrigeration Battery at a store in Los Altos, California.

"Thermal storage is not necessarily something new by any means but what [our supplier] has done is put together a very intelligent architecture to manage a significant load for grocery stores and other like facilities," said Tristam Coffin, director of sustainability and facilities for Whole Foods Market.

Whole Foods runs the system from noon until 6:00 p.m. on weekdays. So far, the system has demonstrated its ability to generate savings of 50 to 120 kilowatts during peak hours, and Coffin expects to see even greater savings going forward.

"Thermal storage solutions can make refrigeration systems smarter or able to respond to fluctuating grid conditions and electricity pricing, which can help refrigerated facilities avoid peak energy pricing. Grocery stores are being penalized for energy use and paying about five times more for power during peak periods of the day," said Amrit Robbins, president and co-founder of Axiom Exergy, the company supplying battery storage to Whole Foods.

U.S. grocery stores operate on slim margins, with net profits after taxes of less than 1.5 percent, which makes reducing energy costs even more important, the Food Marketing Institute said.

"They are spending a tremendous amount on energy and most of that goes to refrigeration," Robbins said. "When we're able to save our customers $30,000 in utility costs, that has the same bottom-line impact of $1.5 million in additional sales. That is like adding an additional month of sales to the calendar year."

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–Amrit Robbins, president and co-founder of Axiom Exergy

Even as the price of energy has fallen over the past few years, peak demand charges have increased. In California, for example, peak charges have increased by 8 to 12 percent per year in recent years, Robbins said.

THE TECHNOLOGY

During a recent webinar produced as part of EPA's Green Chill program, Axiom said it offers a bolt-on retrofit that transforms existing refrigeration systems into low-cost, cloud-connected thermal batteries. "We make it possible for the first time to actively manage refrigeration systems," Robbins said.

A standard, regular battery, either lithium ion or lead acid, stores electricity using electrochemistry. In contrast, Axiom's Refrigeration Battery freezes tanks of saltwater at night when energy is inexpensive. It then uses the frozen tanks to supply cooling services when energy prices skyrocket during peak-use periods. As a result, supermarkets can turn off all their medium-temperature compressors and condensers for six-to-eight hours at a time.

The system also has a proprietary cloud platform that intelligently manages fleets of assets using remote monitoring, data analytics, diagnostics and operational controls. "Rather than trying to sell our customers a big stack of batteries, we transform their existing refrigeration and air conditioning systems into low-cost, intelligent, cloud-connected batteries," Robbins said.

Axiom said the battery can meet medium-temperature refrigeration needs. In an average store, the batteries can reduce peak electricity load by 40 percent.

The battery systems arrive on site fully pre-assembled. "The most time-consuming part is installing the coolant loop between the system integrator and thermal storage tank," Robins said.

EMERGENCY RESPONSE SOLUTIONS

During a power outage, perishable food can start to spoil in under two hours; Robbins said that Axiom's Refrigeration Battery can keep food cold, which can mitigate the risk of food spoilage during a power outage.

"We found that some of our customers are even more excited about the backup cooling application than they are about energy cost reductions," he said. "The holy grail for grocery stores when it comes to resilience is keep the doors open and keep selling groceries even after the power goes out. We get them 55 percent of the way there."

Coffin agreed. "Resiliency is a very, very important conversation we need to be focused on more often than we are," he said, referring to not only catastrophic events but also to brown-out and black-out situations.

The average grocery store contains about $368,000 worth of perishable goods at any time. "A single power outage can be very, very painful," Robbins said.

Axiom Exergy's batteries can provide hours of backup cooling, Robbins said. In order to function during a power outage, the thermal battery storage is paired with a small battery to power the pump, an Internet connection and the evaporator fans in display cases or walk-in evaporators.

THE FUTURE

Coffin said battery technology is gaining new relevance. "In California, our grid is becoming cleaner, but we're still using carbon-based energy sources. Anytime you can reduce demands on the overall grid, there are environmental benefits," Coffin said.

The grid is becoming more and more volatile over time, which is making energy storage solutions more valuable, Robbins said.

Whole Foods is looking at other locations to roll out and wants to include the refrigeration battery in new construction, and he said it could be used in stores with natural refrigerants. "Although the current refrigerant is a HFC refrigerant and that has been the focus to date, there is a lot of opportunity to pilot with natural refrigerants," Coffin said.

The system currently works with HFC refrigerants, but Axiom plans to bring other refrigerants onboard.

Thermal storage could enable the use of CO_2 in hot climates by relieving the stress on CO_2 transcritical systems during higher-temperature days, Coffin said.

Axiom's first fully-installed unit was at the Whole Foods location, and a second pilot is under construction at a Walmart in southern California. "Next year we plan to roll out another five-to-10 units," Robbins said, adding that the company is exclusively focused on supermarkets, but the technology is applicable to every step of the cold chain.

Certain states have more volatile energy pricing, and Axiom is currently focusing on 12 states. "California is the most obvious because it's right in our back yard," he said.

While Whole Foods experienced a 50-kilowatt reduction in use during peak times, Coffin and Robbins believe that could hit upwards of 125 kilowatts going forward.

During some of the testing, they weren't maximizing the system's potential. "This is a pilot for them and us. We understood going in that this was a pilot and there was going to be some lessons learned."

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You think you know what you're doing?

I visit a lot of refrigerated facilities and I've found many of them well prepared for an ammonia incident. The refrigeration operators are trained and knowledgeable in the operation of their systems. Many companies also have others trained to assist in various duties if there is an emergency of any kind. The majority of these facilities do not have specific ammonia response capabilities, but are prepared to take defensive actions to keep their people, the public, and the environment as safe as possible. Some facilities do have people and equipment to carry out a "response" to an ammonia emergency, and they plan and train, so they are prepared. However, I have also found some who think they know what to do and how to properly use their equipment, but they really don't.

I have also found some who think they know what to do and how to properly use their equipment, but they really don't.

Here are a couple of examples. One outside the refrigeration industry and one within it.

Stuck on a ridge.

It was a beautiful day! Clear skies as far as you could see, mild temperatures, and very little wind. He had been in this area before and had gotten some amazing photos of the mountains as the sun set. Although there were no other people in this remote area, he felt comfortable and confident in himself and his gear.

He was high on a ridgeline that was several hundred feet long and that fell off steeply on both sides. It was a breath taking spot. As the sun started to set the colors were amazing, and he took lots of photos. As the sun set he figured he would camp at one end of the ridge. He knew just the spot that would fit his tent. As darkness closed in, he set up his tent, anchored it with a few rocks and then climbed in for a good night's rest. He knew where he was, felt comfortably protected in his tent, and had no concerns as he drifted off to sleep.

While he slept the weather began changing. Late in the night the wind started blowing strongly across the ridge and he awoke with the violent shaking of his tent. He figured he better check the anchoring of his tent so he stepped outside. The snow was blowing horizontal, he couldn't even see a few feet, and he felt like he was going to be blown away by the force of the wind. He turned around to get back into his tent, but it was gone.

In this location and in these conditions trying to hike would likely result in a step off the edge of the ridge and a long, long fall. He had not checked the weather forecast to see that a change was predicted. Had he checked the weather he likely would not have stopped to camp on the ridge, but would have hiked down further into the trees. The conditions he found himself in were extremely serious, even deadly.

The only thing that saved him from dying of hypothermia was he had a cell phone that still had battery life, and fortunately due to his location he still had service. A call to 911 put Search and Rescue in motion, and many hours later they rescued one very cold person who hours earlier had thought he knew what he was doing.

Ammonia response drill

In a visit to a very remote processing plant I had the opportunity to test the response capabilities of the plant personnel to a simulated ammonia incident. Since this facility was remote they had purchased Level A suits, SCBA's, ammonia meters, and other gear so they could respond to an incident, since there were no other agencies close to provide help without a several hour delay. They had sufficient response equipment to suit-up several people, which in their minds gave them better assurance that they could handle whatever came up. They knew they were prepared, and could handle an ammonia emergency.

The first clue I got about their actual preparedness came when I asked about their gas detection meters. They showed me two of them, both of which had not been calibrated in a long time, and neither worked due to failed batteries. Fortunately, they had another meter, but upon checking it I found it in the same condition as the other two. There were no functioning hand held gas detectors for ammonia or the other hazardous gas the facility had.

"Okay", I said, "You need to get these detectors operational very soon. Let's look at your Level A suits." They brought out four of the suits. I looked at the suits and said to the group, "Gather around here, I want to explain something to you." I pointed out, "Notice that these suits do not have boots or gloves attached. Also, notice (as I stuck

my fingers through a ventilation port) that these are not excelation ports to relieve pressure within the suit, but just open holes for some ventilation. These are not Level A suits."

Their response was "Oh." Then after a little thought the Chief Engineer said "I think we do have some Level A suits". After some looking they did find four Level A suits.

I next asked if we could review their SCBA's. They had two different kinds of SCBA regulator systems. A couple of the men were somewhat familiar with their SCBA's so I asked them to demonstrate their use. I have to admit that they did do a seal check, but from there things went downhill. One of the air bottles was not full, and it should have been. A bigger issue was that one of the system regulators kept getting stuck. One refrigeration operator put on the SCBA, but it took him 15 -20 seconds to finally get the air flowing into the mask. Fortunately this was a practice drill and the operator remained calm as he waited for the air to flow.

I next asked the group if some of them wanted to suit up Level A. Many of them volunteered.

The Level A suits had boots, but these are not to be walked on. The flexible boot of the suit should go into an outer, and more protective boot. Their response was again "Oh." The Chief sent a couple of the group out to find rubber boots. Fortunately, the facility had lots of rubber boots.

I stated to the group it takes time and effort to get into a Level A suit, and it is best done with help. I got two men out of the group to help suit up a third person. First they helped the person get on his SCBA. Then they started to put him into the Level A suit. I had to stop them because they forgot about the additional protection that should be put on the hands. I explained to them that the hands are the point of contact for whatever you're doing. They had nitrile gloves in the facility, which I had the helpers put on the person being suited up. Then a cotton glove, then the hands are ready to go in the glove of the suit.

Even though the suits were extra-large it was somewhat of a struggle for some of the guys to get in the suit and for the helpers to completely zip it up. The zipper on a Level A suit does not move with the same ease as a coat zipper, or even a Level-B suit. This was a challenge, but they were finally successful in closing up the suit.

I am not sure how the next thing happened, in fact I didn't even think it could happen. One of the men getting suited up somehow managed to twist the bottom half of the suit 180 degrees. The helpers should have seen this and straightened out the suit. It wasn't discovered until the team of two were ready for their assignment. I looked at that one member of the entry team and asked "How did that happen?" Then "Guys get him out of that suit."

This facility had the people and equipment to respond to an ammonia emergency. They thought they knew what they were doing and how to use the equipment. Neither was true. The Chief Engineer was glad we had done this drill and the whole group realized how much more practice they needed, as well as familiarization with their equipment.

Do you really know what you are doing? In some cases it may not matter, but in emergencies it can make the difference between life and death. Luck is not something you want to base your knowledge and preparedness on.

Foundation Readies for IIAR Conference

In its continuing effort to support the military and introduce skilled workers to the ammonia refrigeration industry, the Ammonia Refrigeration Foundation and the International Institute of Ammonia Refrigeration are inviting transitioning military personnel, National Guard and reservists stationed at Fort Carson, Colorado to attend IIAR's annual conference March 18-21 at the Broadmoor Hotel & Resort in nearby Colorado Springs.

The IIAR conference, the largest exposition dedicated to the ammonia and natural refrigeration industry, will provide military personnel with the opportunity to network with leading manufacturers, contractors, trainers and other service providers, and in some cases, interview for positions within the industry.

"We want to introduce them to key personnel and help them understand how their current skills can translate into this industry," said Lois O'Connor, the Foundation's executive director. "There are over 40,000 jobs open in our industry, and these are people who already have transferable skills from their time in the military. Their skill set and core values match those of our industry. So, this is a commitment to hiring qualified people into a growth industry and a sustainable industry."

Military attendees from Fort Carson will be met by a host committee of military veterans that are currently employed in the ammonia refrigeration industry, from technical and safety management areas to sales, engineering and logistics. They will be divided into groups and assigned specific hosts who will act as mentors, help them navigate the trade floor and make introductions.

"We're excited about the opportunity for our transitioning service members to learn more about the ammonia refrigeration industry," said Sherry Jenkins, career skills program coordinator at Fort Carson. "If there's enough interest, it would be great to explore how we can address the gap in the skills that our transitioning service members have and what's required for entry into the industry. We work hard to develop these types of partnerships with industry that can lead to careers after transition that offer livable wages and opportunities for advancement."

The service members will be invited to a panel discussion regarding the new national standard for apprenticeships, in which Dave Harrison from FASTPORT, along with representatives from food processing, warehousing, manufacturing and contractors, will participate. This will help the IIAR membership and our military guests better understand the opportunities and training available.

Finally, there will be an interview room where companies can meet privately with job candidates.

In keeping with its mission to help transitioning military personnel, the Foundation and the Refrigerating Engineers and Technicians Association announced a partnership earlier this year in a scholarship fund to benefit veterans, National Guard and reservists who wish to study in RETA-certified refrigeration-technician training programs across the country.

"We want to reach out to our veterans because, first of all, it's the right thing to do," O'Connor said. "Our industry has numerous members who are veterans. To reach out to this sector gives us an immediate and logical progression toward developing industry talent."

Founders Scholarship Applications

A reminder to our membership to encourage interns, family and friends to prepare applications for the Founders Scholarship, which is awarded each year to students who exhibit exceptional character and interest in pursuing an engineering or related technical degree leading to a career in the refrigeration field. Junior recipients will be invited to IIAR's 2018 conference. This year, the Foundation increased the dollar amount given to scholarship recipients, as well the actual number of recipients. The Foundation also tripled the application pool by outreach with ASHRAE and the Veteran Student Association to make them aware of our programs and initiatives.The Founders Scholarship honors the legacy and significant contributions to the ammonia refrigeration industry of George Briley, Chuck Hansen, Don Niederer and Bill Richards as the primary founders of IIAR.Deadline for applications is Memorial Day, Monday May 28, 2018

RUB OF THE GREEN

The third annual William E. Kahlert Memorial Golf Tournament is scheduled for March 17 at the Cheyenne Mountain Resort in Colorado Springs. Last year's tournament grossed more than $80,000, with 77 golfers teeing it up, and the EVAPCO team taking home first place.

This tournament is a great way to spend quality time with colleagues, as well as current and future customers. All proceeds from this event support the mission of the Foundation.

We encourage companies to sign up as sponsors and players to register for what will be a great day on a championship golf course. Please visit our website for sponsorship opportunities and to register teams.

ANNUAL GIVING

Finally, please remember that as a 501(c)(3) educational and research organization, the Foundation depends upon the tax-deductible financial support of individuals, corporations and foundations. Donors who reach an annual cumulative donation level of $150 or more during the fiscal year are recognized through the year in a variety of ways for their commitment to the advancement of The Foundation and its mission. We thank everyone for their support and remind you that the foundation depends on your generosity.

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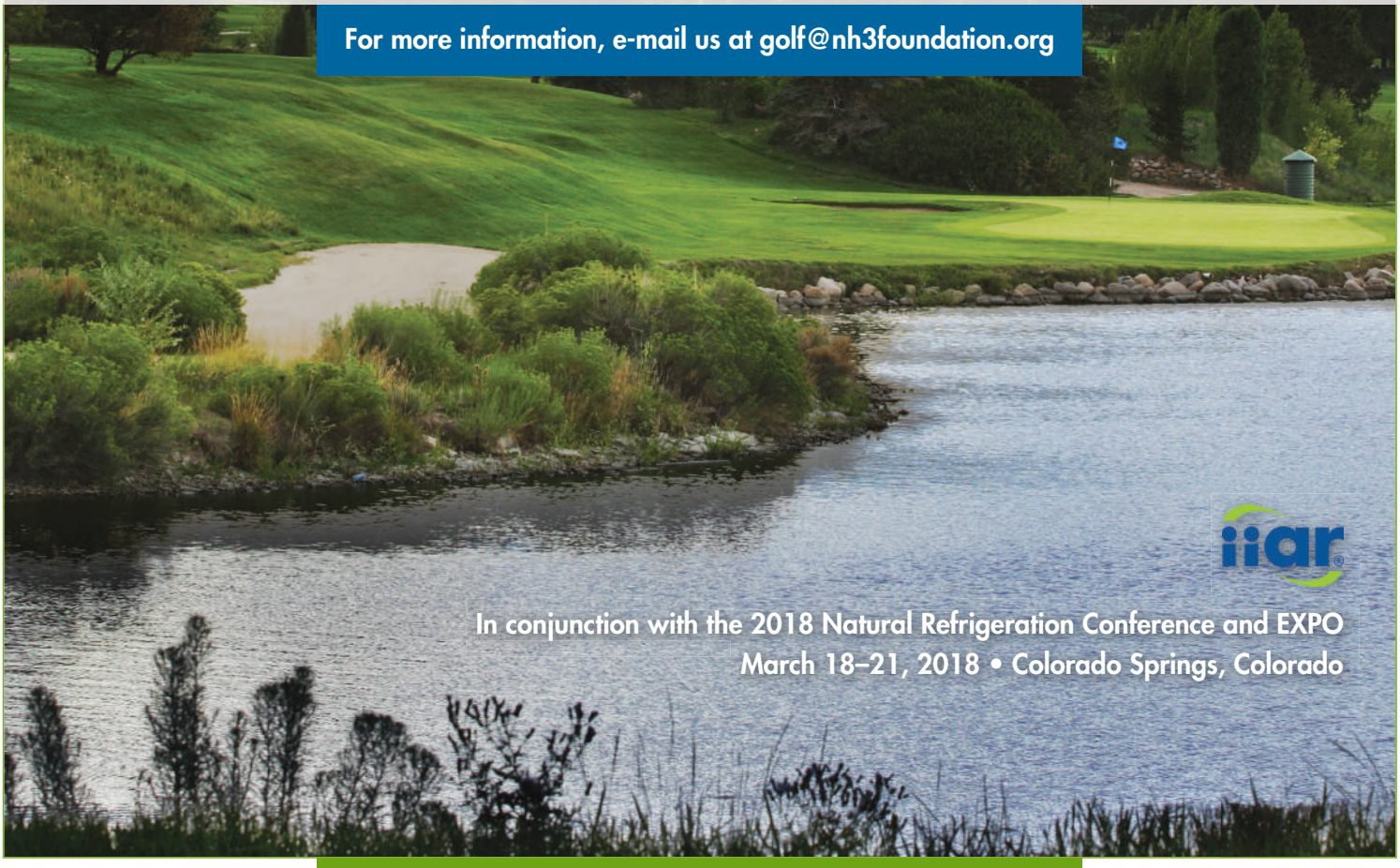

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Ammonia and Bad Oil Don't Mix

Oil and ammonia mix continuously in refrigeration compressors. The primary function of the oil is to lubricate and cool the compressor, but a small amount of oil is always circulating with the refrigerant that leaves the compressor. This oil comes in contact with all components of the refrigeration system, a fact that must be considered when replacing compressor oil.

Clearly, oil plays a critical role in protecting compressors, ensuring optimum performance and life of the system. Often overlooked is what impact many important lubricant properties have on other parts of the refrigeration system and the vital importance of using the right oil.

The use of oil not proven to work with ammonia has led to issues for end users in the ammonia refrigeration industry, causing compressor failures, contaminating systems and in some cases increasing safety concerns. As an example, lubricants with high aromatic content or excessive foaming tendency increase oil carryover and increase the frequency of required oil draining from a system's low-side components.

Also, oils with wrong aniline point can lead to gasket swelling or shrinkage with resultant ammonia or oil leaks.

"Oil moves all around the system in small amounts, so it can cause problems throughout the system if it's not tested and proven for all the different components," says Joe Pillis, Director of Technology for Industrial Refrigeration at Johnson Controls. "Refrigeration oils have a much bigger job than just lubricating the compressor."

Third-party lubricants not tested for ammonia compatibility may contain unproven or harmful additives. When unproven oil additives react with ammonia, the result can be unpredictable. "Deposits sometimes form that can plug orifices and prematurely wear shaft seals and bearings," Pillis says. "People don't think about all this when they choose an oil. They just think, 'Isn't all oil the same?'"

Deposits or sludge in the filters and separators increase pressure drop and hurt efficiency. "I have seen cases where oil separators had to be cut apart to remove solid sludge from such a reaction," Pillis says.

Refrigeration oils need to have proper viscosity and viscosity index for anticipated operating temperatures. Too low viscosity can shorten bearing life, while too high can increase frictional power consumption. Too high a pour point can foul heat transfer surfaces or impair oil recovery from re-circulators, reducing system efficiency or reducing capacity. Very low pour points generally don't hurt performance, but can triple oil price and be a waste of money for higher evaporator temperatures.

Previously, most reciprocating compressors for ammonia systems used naphthenic oils, chosen because of their natural low pour point of around minus-30 degrees. However, their low viscosity index, high volatility and high aromatic content resulted in high carry-over. Carbon and sludge buildup impacted compressor performance and maintenance and required frequent oil changes. Today's screw compressor systems run much lower discharge temperatures and it is rare to actually "wear out" oil.

With proper filtration and oil analysis, it is possible for refrigeration oils to run for many years without replacement. The incentive to change from the original equipment manufacturer's oil to lower cost aftermarket alternatives is very low when oil rarely needs to be changed.

Pillis recommends an OEM-supplied oil that has been tested and proven for long-term use with ammonia. OEM-supplied oil may have a high viscosity index that provides temperature stability and reduces vaporization of oil into the discharge side of the compressor. The viscosity of the lubricant changes less as temperature increases, keeping viscosity in the proper range for various sections of the compressor.

OEM-supplied oil may have lower aromatic content, reducing volatility and resulting in less carry-over loss into the system. With lower levels of the more volatile components of the oil — to vaporize at operating temperatures — viscosity increase does not occur, and the oil stays in proper viscosity grade thousands of hours longer than other oils. This can extend compressor life and extends the drain interval.

Although OEM-supplied oil may be more expensive than a third-party aftermarket oil, end users can be confident that it will not damage key system components. "Buy an oil from somebody you can trust, who has been in the business and understands ammonia and your equipment," Pillis says. "There are still people out there selling oil that's untested in ammonia refrigeration systems and it causes problems.

"I also caution users about putting any aftermarket 'efficiency improving' additives into their compressor oil. These have often led to equipment failure and expensive clean-ups," he says. "If someone claims they can improve your system efficiency by 20 percent by putting their 'magic additives' into your system, the best advice is to run the other way and lock the engine room door."

The Inheritance Talk

The IIAR and ARF reserve investment funds are currently managed by Stifel Financial Services under the investment policy established by their respective board of directors. In this and subsequent issues of the Condenser, you'll find a "financial tech tips" article from the firm on this page. Members of IIAR may use the financial services of Stifel for personal and business investments and take advantage of the reduced rate structure offered with IIAR membership.

Losing a loved one can be one of the most challenging experiences of a person's life. While grieving, a person must complete many burdensome tasks, such as planning a funeral. Receiving an inheritance during this time can be the source of even more stress, as the recipient must determine how to access and manage the inheritance. This process can seem especially daunting if the recipient needs the inheritance to help cover the decedent's debts or final expenses. Luckily, the stress caused by an unexpected inheritance is avoidable.

Although it may be uncomfortable, discussing your well thought-out estate plan with your heirs can alleviate future stress. On the other hand, avoiding this discussion could leave your beneficiaries unprepared to handle the family's wealth. According to a study by The Williams Group, 70% of wealthy families lose their wealth by the second generation and 90% by the third generation. To ensure that your heirs preserve your family wealth for generations to come, consider the following.

Although it may be uncomfortable, discussing your well thought-out estate plan with your heirs can alleviate future stress. On the other hand, avoiding this discussion could leave your beneficiaries unprepared to handle the family's wealth.

IDENTIFY FAMILY VALUES

Educate your family and heirs about your priorities. What are your goals? How do you prioritize these goals? The best way for your beneficiaries to understand your values when it comes to wealth is to lead by example. Do you give to charity? Plan family vacations? Save a portion of each paycheck for a rainy day? Show your family what is important by having these discussions and providing them with a good example throughout your life.

CREATE A PLAN

Consider how to approach this discussion. Would you rather talk casually at the dinner table or in a formal setting at your advisor's office? Start developing this strategy ahead of time so that you are prepared to have this discussion. Do you want to talk to your beneficiaries one-on-one or invite them all for a family meeting? Decide who you want to lead the discussion and how you can help prepare your heirs to manage the wealth you have accumulated throughout your career.

HOW MUCH SHOULD YOU SHARE?

Deciding how many details to share about your wealth can be difficult. This goes hand in hand with the maturity of the individual. If your heir has a pattern of irrational spending, it might not be the best time for full disclosure. On the other hand, if you have a fiscally responsible heir, you may feel comfortable providing them with more details.

WORK WITH PROFESSIONALS

Work with your Financial Advisor, CPA, and estate planning attorney to ensure that your wealth will be transferred in the most efficient way possible. Together, you can determine if it is better to make lifetime gifts or transfer everything upon your passing. This is also the perfect time to introduce your heirs to your trusted advisors. Let your children know who to contact in the future (or now if they are ready to start planning for their own retirement).

There is no time like the present to prepare your heirs to manage your wealth after you are gone. Have these discussions now to ensure that your heirs don't blow their inheritance like one in three Americans (as indicated by an Ohio State research study).

The IIAR and ARF reserve investment funds are currently managed by Stifel Financial Services under the investment policy established by their respective board of directors. Members of IIAR may use the financial services of Stifel for personal and business investments and take advantage of the reduced rate structure offered with IIAR membership.

For additional Wealth Planning assistance contact your Stifel representative: Jeff Howard or Jim Lenaghan at (251) 340-5044.

Proper Training Around Repair Procedures is Essential

A recent fatal accident, as well as reviews of previous problems, emphasized the critical importance of proper training, experience and clear-cut procedures when conducting repairs of ammonia refrigeration systems, leading industry observers said.

Often repairs must be done in time-critical situations, and technicians must resist pressures to take short cuts, they said.

In October, three men died at an ice skating rink in Western Canada while completing emergency repairs to the rink's refrigeration system. Although the investigation is ongoing, and no formal results have been released as to the cause, the tragedy is a reminder of the critical importance of proper training and experience, and the need to establish clear cut procedures when preparing equipment for maintenance or conducting line breaking operations.

"While we don't want to speculate on the reason for the accident in Canada, unfortunately, the industry has incurred many serious accidents during emergency or even normal repairs or line breaking where people simply didn't follow the appropriate or reasonable safety practices," said Peter Jordan, Senior Principal Engineer, MBD Risk Management Services, Inc.

In some cases, pressure from production personnel to bring the system back online results in shortcuts. "They're down for maintenance for the weekend, they shut off the storage freezer, and now it's getting warm because they've been working on the system for two days," said Bob Czarnecki, former program manager of refrigeration at Campbell Soup Company and current chairman of the IIAR Standards Committee. "They feel like they need to get the system back online, so they look at an isolation valve where they can't stop it from leaking through, for example, and they decide to blow the ammonia out a different way or put on a mask and just weld it."

There are four critical elements to safely operating and maintaining an ammonia refrigeration system, Czarnecki said. It begins with training. With training comes knowledge, and in time, experience follows. Once those three core elements are established, the importance of adhering strictly to established procedures is understood.

Training is available through a variety of sources. The International Institute of Ammonia Refrigeration offers a complete suite of design and safety standards, video instruction and other technical publications to provide regulatory and safety guidance for ammonia systems. In addition, its Academy of Natural Refrigerants will soon introduce a new certificate course curriculum designed to provide personnel working in the industry with comprehensive training in ammonia systems. The "Academy of Natural Refrigerants Specialist" (ANRS) certificate will enable engineers and operators to expand their professional credentials and training in three major areas of standards, ammonia safety tracks and basic engineering courses. The Refrigeration Engineers and Technicians Association (RETA) also offers courses to provide operators and technicians with specific training for ammonia systems from introductory to advanced levels of certification.

"A person who does not have the knowledge or experience, or is not familiar with operating procedures shouldn't touch an ammonia refrigeration system," Czarnecki said.

Line breaking, which is the process of opening the system to the atmosphere usually for maintenance or system modifications, is one of the main causes for ammonia incidents when executed improperly, Czarnecki said. "Following the line-breaking procedure is very important because it gives you a step-by-step process that ensures a pipe or other piece of equipment is free of ammonia before you work on it," he said. "But that can take days, and that's where the danger of shortcuts come in."

Before undertaking a line-breaking procedure, it is important to isolate the specific area of the system to be worked on, and determine a safe way to remove the ammonia before beginning the maintenance operation. Otherwise, incidents can take place, such as one reported a few years ago when a small pressure vessel needed to be replaced. "It was on a platform on the roof, with pipes attached to the vessel and ammonia behind that at high pressure," Czarnecki said.

"They should have blanked off all the valves that were being disconnected from the vessel and made certain the valves behind it were closed. But they didn't do that. Workers were standing on the pipes, and one worker stood over a valve handle and twisted it, and all this ammonia came flying out. A worker was seriously burned, and it was all because they didn't follow the proper procedures to make sure nothing could come out of that pipe."

Jordan and Czarnecki recommend that procedures be thoroughly reviewed before beginning maintenance operations. "Go through it step-by-step, and then make certain you follow the procedure exactly as you laid it out," Czarnecki said. "People can become complacent. They just think they're going to change a relief valve, for example, when what they should first do is sit down with their supervisor or contractor and detail exactly what they are going to do. Even though it sounds routine, you should still go over each and everything when opening up the system and exposing yourself to ammonia."

In the end, regardless of the size of the system or the engineering controls in place, the safety of the system ultimately depends on the knowledge of the people who operate and maintain it, and the assurance that they will follow proper procedures, avoiding shortcuts that could lead to incidents.

"The moment you take shortcuts you're in trouble," Jordan said.

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CFATS Program Change Simplifies Top-Screen

Recent adjustments to the Department of Homeland Security's Chemical Facility Anti-Terrorism Standards (CFATS) program have simplified the process of completing a risk-assessment, known as a Top-Screen, and could result in changes to how an ammonia refrigeration facility is categorized under the program's tiering system.

DHS, in conjunction with IIAR, recently held a webinar that focused on when and how industrial ammonia refrigeration facilities must report to DHS. Presented by Kelly Murray, the Standardization and Evaluation Section Chief for *DHS*, the webinar unveiled a revamped tiering methodology and a streamlined Top-Screen model.

During the rollout, DHS has reached out with notifications sent to the 27,000 facilities of chemical interest in the country. DHS inspectors have met with local emergency planning committees and visited with chemical manufacturers and distributors. Ammonia refrigeration facilities with more than one percent concentration and 10,000 pounds of ammonia are required to submit a Top-Screen.

"Some facilities don't realize they are supposed to report, so we are trying to assist them in adhering to the program," Murray said. "We're taking a softer approach in helping them understand their obligations before any enforcement [takes place]."

DHS identifies a facility's level of risk using information submitted by facilities through Top-Screen, which takes into account vulnerability, potential consequences and the threat of a terrorist attack. Facilities are then placed into one of four tiers, with Tier 1 representing the highest risk. Under the revised tiering methodology, which was reviewed by industry and government experts, facilities can move from higher to lower tiers, or vice versa. They can also become un-tiered or newly tiered.

A facility's tier can change based on a revised Top-Screen submitted to DHS. For example, a tier determination may change if:

Facility operations change significantly. This could include the removal or addition of chemicals of interest, changes in operations or processes, and/or changes in threats or vulnerabilities. Such changes typically would be site-specific and will be reviewed on a case-by-case basis. When a facility makes a material modification to its operations or site, it must submit a revised Top-Screen within 60 days. Following the submission, DHS may require the facility to submit supporting documentation.

Resubmission of a Top-Screen reveals changes in threat, vulnerability or consequence. Facilities with approved Security Vulnerability Assessment (SVA) and Site Security Plans (SSP) are required to resubmit Top-Screens every two years for Tier 1 and 2 facilities and every three years for Tier 3 and 4 facilities.

In rare cases, DHS considers new information about a site, chemical, threat or process that warrants revising an existing facility's tier upward or down. DHS will provide appropriate notification to the facility of the reasons justifying a change in the facility's existing tier.

Tiering is not solely dependent on the chemical of interest, but also depends on the toxicity of the chemical, the population and topography surrounding the facility, the quantity and concentration of the chemical, the pressure rating and temperature of the tanks, and the secondary containment. Although the specifics of what determines tiering is classified information, Murray said that some facilities that were previously tiered will be removed, while others that were not tiered will become tiered.

"That is primarily due to changes in plume modeling and how we are looking at the plume over the population in those areas," she said. "Previously, we would average the population across the plume. With the new model, we look at exact data points of that population. Before, if the population was far away from the facility but within the plume, we were perhaps overestimating the risk. If the facility had a population that was directly around the plume, we were potentially underestimating the risk, because of averaging it out."

There have also been significant changes for how facilities submit the Top-Screen, making it easier to take the first step in the CFATS process. "With the old Top-Screen tool you had to go through every chemical and check 'yes or no'," Murray said. "Now, you can type in the appropriate chemical (such as ammonia) and immediately find it. The burden has been reduced by around 75 percent."

Previously, facilities were also required to insert data points at each location that has ammonia. But that has also changed. "We recognize that temperature, pressure and concentration ranges can change throughout the system, so rather than require the facility to have a data point for every single option that could take place, we are allowing them to use the temperature, pressure and concentration in other aspects of the process, and wherever the final point is in the process, they are allowed to use that total quantity," Murray said.

On its website, DHS has an instruction manual with a list of frequently asked questions specific to ammonia to guide facilities through the Top-Screen process. If a facility becomes newly tiered, Murray said, it should assess its chemical inventory, and if at 10,000 pounds or higher, to immediately begin filling out the Top-Screen, and seek the help of DHS inspectors.

"And lastly, don't panic," Murray said. "The vast majority of facilities are completing the Top-Screen in 10 minutes or less. It's actually very easy."

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Tax Reform Takes Center Stage

iiar government RELATIONS

BY LOWELL RANDEL, IIAR GOVERNMENT RELATIONS DIRECTOR

Tax reform has emerged as the top priority in Washington, DC as President Trump and Congressional Republicans set the goal for passing legislation before the end of 2017. Republican leaders are feeling pressure to secure a signature legislative victory following the failure to repeal and replace Obamacare. As a result, the House of Representatives and Senate have worked during the fall of 2017 to develop and advance a package of tax reforms. These efforts culminated during the week of December 18, 2017, when a final tax reform package was approved.

The new tax policies will have a major impact on businesses operating in the United States, as well as all individuals living in the United States. Below is a comparison of the major business tax provisions and an analysis of how they would impact industry:

CORPORATE TAX RATES

Under the final package, rate for "c" corporations would drop from the current level of 35 percent to 21 percent. The new rate goes into effect on January 1, 2018. This is arguably the most positive policy change for companies in the industrial refrigeration industry. Before the reduction, corporations in the United States faced the highest corporate tax rate of industrialized nations. A permanent reduction in the corporate tax rate will help reduce the tax burden on U.S. corporations and make them more competitive on the global stage.

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PASS-THROUGH BUSINESS TAX RATES

Provisions related to pass-through businesses were hotly contested during consideration of the bill. The House established a very complex system for calculating taxes for pass-through businesses, while the Senate took a relatively simpler approach. The final package follows the Senate approach, with some modifications. Individual taxpayers would be eligible to take a 20 percent deduction on qualified business income from a partnership, "s" corporation or sole proprietorship. This applies for up to 50 percent of the W-2 wages of the taxpayer who has qualified business income from a partnership or "s" corporation (with some exclusions and phase in for couples earning less than, or slightly more than, $350,000 or individuals making less than, or slightly more than, $157,500). The bill would also allow specified service businesses to utilize the 20 percent deduction in cases where taxable income is less than $350,000 for married couples and less than $157,500 for individuals.

Pass-through provisions had the potential to derail the bill in both the House and Senate, as many small businesses advocated raised concerns that they would be disadvantaged compared with "C" corporations. Some policy makers were reluctant to make the pass-through provisions more generous, because they could incentivize high-income taxpayers to attempt to convert wages or other compensation for personal services to income eligible for the 20-percent deduction under the provision. The final bill is intended to strike a balance between these concerns, recognizing the importance of giving tax relief to small pass-through businesses, while deterring larger pass-throughs from converting wages to business income eligible for the 20-percent rate.

CORPORATE ALTERNATIVE MINIMUM TAX

The final agreement repeals the corporate alternative minimum tax. In the case of a corporation, the agreement allows the AMT credit to offset the regular tax liability for any taxable year.

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In addition, the AMT credit is refundable for any taxable year beginning after 2017 and before 2022 in an amount equal to 50 percent (100 percent in the case of taxable years beginning in 2021) of the excess of the minimum tax credit for the taxable year over the amount of the credit allowable for the year against regular tax liability. The full amount of the minimum tax credit will be allowed in taxable years beginning before 2022.

INCREASED BONUS DEPRECIATION

Companies will be able to immediately write off the full cost of investments in their businesses, starting with assets purchased and placed in service after September 27, 2017 and before January 1, 2023. The write off percentage would then phase out between 2023 and 2027, going down by 20 percent each year.

In addition to the lowering of tax rates, the increased exemptions of the estate tax, along with several other favorable business tax policies should provide benefits across the industry.

ESTATE TAX

The legislation retains the estate tax, but significantly increases the exemption thresholds. Starting in 2018, the estate tax exemption starting for single individuals doubles from $5 million to $10 million and for married couples from $10 million to $20 million. The amounts will be indexed to inflation occurring after 2011. The new thresholds go into effect on January 1, 2018 and expire at the end of 2025.

The doubling of the exemption levels will help many small businesses who have a larger estate than the current exemption levels. However, much effort in Washington has been placed on repealing the estate tax and many are disappointed that the final package does not include a full repeal. It is also concerning that the increased thresholds expire at the end of 2025, setting up the potential return to lower levels if Congress does not take action.

Companies with plans for investment during the five-year window can take advantage of the 100 percent depreciation allowance. This can be a useful tool for companies to realize the available depreciation benefits of capital expenditures fully in the first year. However, the restricted time window limits the scope of the benefits.

RESEARCH AND DEVELOPMENT CREDIT

The Research and Development Credit is retained.

EXPANDED AVAILABILITY OF CASH METHOD OF ACCOUNTING

The ceiling for cash method of accounting is increased from $5 million average gross receipts to $25 million.

NEW EMPLOYER CREDIT FOR PAID FAMILY AND MEDICAL LEAVE

Creates a new credit for wages paid to employees on FMLA if certain conditions are met. However, this credit is only effective for 2018 and 2019. An eligible employer is one who has in place a written policy that allows all qualifying full-time employees not less than two weeks of annual paid family and medical leave, and who allows all less-than-full-time qualifying employees a commensurate amount of leave on a pro rata basis.

DEDUCTION FOR BUSINESS INTEREST

Effective in 2018, businesses would only be able to deduct net interest expenses incurred by a business up to 30 percent of the business's adjusted taxable income.

SMALL BUSINESS EXCEPTION FROM LIMITATION ON DEDUCTION OF BUSINESS INTEREST

Effective in 2018, companies with average annual gross receipts of $25 million or less would be able to continue to deduct business interest.

SUMMARY

Congress and the Administration successfully raced to complete tax reform by the end of 2017, handing Trump and Congressional Republicans a much-needed legislative win. Many industrial refrigeration companies operating in the United States will stand to benefit under the news tax structure. The lowering of the corporate rate to 20 percent will be an automatic benefit to "c" corporations. For pass-through businesses, the calculation of impacts is more complicated, but still an improvement over the current rates these companies face. In addition to the lowering of tax rates, the increased exemptions of the estate tax, along with several other favorable business tax policies should provide benefits across the industry.

Assessment of Lubricants for Ammonia and Carbon Dioxide Refrigeration Systems

GLENN D. SHORT, PRESIDENT, BVADVANCED DIVISION; TECHNICAL DIRECTOR, BVA INC.

ABSTRACT

Ammonia (R717) and carbon dioxide (R744) have received increased recognition as non-ozone- depleting and low global warming potential refrigerants. In some cases, both of these refrigerants are used in a cascade system. Some properties of refrigerant-lubricant mixtures are very important for the design and performance of compressors and the refrigeration cycle. Low solubility of a lubricant with a refrigerant can improve the compressor's performance. The use of miscible or nonmiscible lubricants can bring different technical advantages for the performance of the refrigeration cycle.

Examination of a lubricant's chemistry, miscibility, solubility, and viscosity with a refrigerant helps system engineers find the best overall balance of good compatibility, lubricity/load-carrying performance, and system performance. R717 data are presented with immiscible mineral oil and synthetic hydrocarbon lubricants and a miscible polyalkylene glycol lubricant. R744 data are presented for miscible polyol ester and polyalkylene glycol derivative lubricants and immiscible synthetic hydrocarbon lubricants.

Introduction

The purpose of a refrigeration oil is to lubricate the compressor and mechanical seals and to provide a seal to the compression chamber. The lubricant may also serve as a heat transfer fluid to remove part of the heat of compression in rotary screw compressors, or to help contribute to electric motor cooling inside hermetic and semi-hermetic compressors. Lubricants are an important design component for compressors.

Original equipment manufacturers (OEMs) are paying increased attention to two "natural" refrigerants, ammonia (R717) and carbon dioxide (R744, CO_2). This paper will discuss the current types of lubricants used with these two refrigerants and emphasize new information that may be of interest to compressor designers and end users. Much previous literature on lubricants for these applications will be summarized to ensure an understanding, but will not be restated in detail.

The design of the lubricant itself is important as many different base stocks and additives are available to formulate the final product. The selection of the lubricant and its formulation must consider many different characteristics of performance.

OVERVIEW OF LUBRICANT TYPES AND PROPERTIES

Base fluid

The most common types of base stocks used in refrigeration include mineral oils and synthetics:

- Mineral oils (MO),
- Alkylbenzene (AB),
- Polyalphaolefin (PAO),
- Polyalkylene glycol (PAG) and fully end capped polyalkylene glycols,
- Polyol ester (POE), and
- Polyvinyl ether (PVE).

The American Petroleum Institute (API) produces a chart that classifies the different base oil types, see Table 1.

Highly refined dewaxed naphthenic mineral oils were historically used with CFC- and HCFC-type refrigerants due to their improved miscibility and low pour point and are still used in ammonia applications. Paraffinic mineral oils are more commonly used with ammonia due to their lower solubility and higher viscosity index.

Group II and III mineral oils have often been termed semi-synthetic lubricants or high-viscosity index hydrotreated oils. These are generally paraffinic oils. In the United States Group III may be called a synthetic lubricant. These lubricants in general have improved stability as a result of their higher degree of saturation and by definition have a higher viscosity index than Group I paraffinic oils.

Synthetic lubricants have very different chemistries that result in the availability of a wide range of physical characteristics such as viscosity, viscosity index, pour point, and lubricity. They also offer flexibility in their design for use with refrigerants with respect to solubility, miscibility, surface tension, lubricity, etc.

VISCOSITY AND VISCOSITY INDEX

The viscosity of a fluid is its resistance to flow, which is directly affected by the temperature of the liquid. It decreases (thins) with increasing temperature and increases (thickens) with decreased temperature. Viscosity is important as it indicates the lubricant's ability to create and maintain a lubrication film between two moving surfaces to prevent wear or provide a sealing effect. A lubricant's viscosity is most commonly measured as kinematic viscosity and expressed in centistokes (cSt). The viscosity at 40 °C and 100 °C is then used to determine the viscosity index (VI) of the lubricant. OEMs specify the required viscosity grade for use in their equipment with a given refrigerant. The grade for refrigeration lubricants is usually defined as the ISO viscosity grade as defined in International Standard ISO 2909:2002, which is nominally defined as the viscosity at 40 °C +/- 10%. The VI measures the change of viscosity with respect to temperature. The higher this number is, the less the lubricant viscosity changes with temperature.

As the lubricant in a refrigeration system is in intimate contact with the refrigerant, some refrigerant will always be dissolved in the lubricant. As the viscosity of a refrigerant is very low, the effect is to cause a significant reduction in the viscosity of the lubricant/refrigerant mixture. The more soluble the refrigerant in the lubricant, the greater the loss in viscosity. Reduced viscosity is a concern as the lubricant may not be able to provide sufficient film strength for separation of the moving parts, leading to increased wear and failure.

POUR POINT

The pour point of a lubricant is the lowest temperature at which a lubricant will flow. Although using a lubricant with a pour point lower than the lowest system temperature is deemed desirable, it is not essential provided the lubricant is at least slightly soluble with the refrigerant. The addition of the very low viscosity refrigerant, acting as a solvent to the lubricant, will cause a significant depression of the pour point. This usually provides sufficient mobility of the lubricant for system requirements.

Note that pour point values can vary for any lubricant type. Manufacturers provide typical data and may also provide a specification listing the maximum value for a specific product. The specification value may be much higher than the typical value so that the lubricant formulator can consistently pass quality control standards. This is particularly true for mineral oils where refineries depend on a various crude oil sources for their production. A higher degree of refining and wax removal provides a greater consistency in the final product.

REFRIGERANT/LUBRICANT MISCIBILITY

This is a measurement of the temperature at which a defined concentration of lubricant in refrigerant mixture changes from a single-phase mixture to a two-phase mixture. The lower critical solution temperature is usually used as a guide to the lowest operating temperature of that lubricant/refrigerant combination.

REFRIGERANT/LUBRICANT SOLUBILITY AND VISCOSITY

Dilution of the lubricant by dissolved refrigerant significantly reduces the viscosity of the pure lubricant. The solubility of a refrigerant in a lubricant can be measured in various ways. The preferred procedure is to take hundreds of measurements in pressure cells at various temperatures and pressures representing the expected operating

Table 1. API base stock categories.

Group	Saturated weight %	Sulphur weight %	Viscosity index
I	< 90 and/or	> 0.03	> 80 to < 120
II	≥ 90 and	≤ 0.03	≥ 80 to ≤ 120
III	≥ 90	≤ 0.03	≥ 120
IV	All polyalphaolefins (PAOs)		
V	All base stocks not included in Groups I–IV		

range and to measure the viscosity with a computer collecting the data (Spauschus and Henderson 1990; Seeton 2006). The vapor pressure of the refrigerant/lubricant mixture provides a measurement of solubility. Liquid viscosities of the mixtures are related to lubricity. Mathematical models can then be used to plot the data on standard ASTM viscosity charts. Density information for the refrigerant/ lubricant mixtures may also be obtained and plotted. The data results are presented in the form of pressure viscosity temperature (PVT) charts, also called "Daniel charts," a viscosity-temperature chart that contains an overlay of the solubility of the refrigerant/lubricant mixture.

PVT charts often use bar as a measurement of pressure. Often no reference is provided as to the relationship of this pressure to atmosphere or vacuum. If not noted, this is bar, absolute or relative to vacuum. The bar is a metric unit of pressure, but not part of the International System of Units (SI). 1 bar = 100 kPa (in SI units).

STABILITY

Exposure of the lubricant to high temperatures in the presence of air causes oxidation. The result of oxidation is the formation of sludge, particulates, and deposits that will increase the viscosity of the lubricant. In addition to the increase in viscosity, these oxidation products also increase the pour point of the degraded lubricant.

Refrigeration oil and other materials used with refrigerants should have thermal and chemical stability to maintain the system reliability. ASHRAE 97:2007 is a common test used for this evaluation. A sealed glass tube containing metal coupons in a lubricant/refrigerant mixture is heated at various test temperatures and durations. Measured amounts of water may also be added to test hydrolytic stability.

Other tests such as the autoclave allow larger quantities of lubricant to be tested with various materials and specimen sizes. ASHRAE is developing Guideline 38P:2015 for this purpose. The use of a metal pressure vessel may be safer for testing at higher pressures and temperatures. The lubricant, refrigerant, and materials may then be examined for any change in physical or chemical properties. The amount of sediment may also be reported.

The total acid number (TAN) is a measurement of acidity that is determined by the amount of potassium hydroxide in milligrams that is needed to neutralize the acids in one gram of oil. It measures acidic constituents that are present as additives or as degradation products formed during service, such as oxidation products. For example, an increase in TAN is often used as a reference to observe the amount of degradation of a lubricant in the stability test. Acid number reflects the total acidic components including organic and inorganic acids, esters, phenolic compounds, lactones, resins, salts of heavy metals, salts of ammonia with other weak bases, acid salts of polybasic acids, and additional agents such as inhibitors and other additives. Evaluation of acid number is particularly important for carbon dioxide systems due to the potential issues with moisture as will be discussed. Instruments such as Fourier transform infrared (FTIR) spectroscopy are also useful to detect lube degradation by-products and additives within lubricating oils.

LUBRICATION

To develop the lubricant, considering the strengths and weaknesses of the selected base stocks and additives relative to the required lubrication performance is necessary. Screening tests such as laboratory tests simulate as closely as possible the conditions within the compressor or differentiate the fluid performance within the compressor. Examples of wear tests employed as a screening test to evaluate these lubricants are a combination of 4-ball (single ball rotated in contact with three fixed balls—IP239) and Falex (pin rotating between two fixed V-blocks—ASTM D2670).

These tests are often modified to include testing under a refrigerant atmosphere. Friction coefficient may be determined in tests such as the pin-on-disc. These tests are usually then followed by compressor tests and field experience.

ADDITIVES

Refrigeration lubricants may or may not require the use of additives, which have various purposes. A minimal amount of additive may be included to extend storage life. More additives may be used to provide a product with enhanced stability, improved wear protection, improved corrosion resistance, or reduced influence on materials. Additives must be designed to be compatible with the refrigerant and the refrigeration system.

AMMONIA (R717) COMPRESSOR LUBRICANTS

Mineral oils and synthetic hydrocarbon lubricants have low solubility and miscibility with ammonia. This is a benefit in flooded evaporator systems as these oils are heavier than ammonia and can be easily removed by draining from the bottom of evaporator vessels. Synthetic and semi-synthetic oils have been developed for optimum performance in these systems.

Returning the oil from the low-pressure side of an NH3 system is potentially dangerous if water is present in the system. A high risk exists of returning water accumulating in the oil or below the oil, sealed from the NH3 by the oil, directly into the compressor. Returning high amounts of water into compressors can give serious problems especially with roller and ball bearings. Returning oil from the low-pressure side to the compressors in an NH3 system is not recommended unless a water removal system or other means of controlling the water level in the NH3 is present.

Immiscible synthetics oils such as highly processed mineral oils, PAOs, and ABs have been used in traditional ammonia systems where their excellent low-temperature properties allow for operation at very low temperatures. Quite often, blends of mineral oil with synthetic or blends of different synthetic lubricants will be used to optimize performance. More recently, the development of ammonia-soluble or ammo-

nia-miscible lubricants have allowed direct expansion evaporators (DX) to be used. These are usually based upon PAG-type chemistry. Polyol esters and other esters are known to react chemically with ammonia to form solids and are therefore avoided.

IMMISCIBLE LUBRICANTS FOR AMMONIA

High viscosity index (HVI) hydrotreated (HT) oils and PAOs were proposed as the preferred base fluids for ammonia refrigeration systems more than 30 years ago (Short 1985) after several years of field experience proving their benefits. Since then, these HVI paraffinic mineral oils have been classified by the API as Group II and Group III. Several additional contributions have added to the knowledge of these lubricants (Dolson and Morimoto 1995; Oberle and Rajewski 1997; Rajewski and Lilje 2000; Dolson 2001). The described advantages of these lubricants when properly refined include

- High viscosity index;
- Low solubility with ammonia;
- Low miscibility with ammonia;
- Improved thermal, chemical, and hydrolytic stability;
- Low volatility in relation to viscosity;
- Low solubility with water;
- Low foaming;
- Excellent response to additives (pour point, inhibitors); and
- Good lubricity and oil film characteristics in ammonia systems.

While these advantages apply to Group II and III type mineral oils and PAOs, PAOs also have very low pour points and are used in low-temperature applications. Note that new technologies have made producing PAOs with even lower pour points than those commonly used and with even higher viscosity index possible, although generally at a higher cost.

Alkyl benzene (AB) synthetic oils found their beginning in the potential deficiency of naphthenic oils. This type of synthetic is based on hydrocarbon chemistry and is similar to a high-aromatic-containing naphthenic oil. The major advantages of this material are its greater stability than its naphthenic counterpart, a lack of wax content, and improved lower temperature properties. AB lubricants were initially used in heavy-duty ammonia compressors with very high outlet temperatures as they produce less "coke" and sludge. They also tended to foam less at start-up. In some cases, compressor OEMs have found using one lubricant for several types of refrigerants desirable as the ABs have excellent miscibility with halocarbon refrigerants. Additionally, these OEMs may be able to use one type of elastomer without concern of a variation in seal swell or hardness changes caused using different lubricants. By 1982, finding partial synthetic refrigeration oils that contained alkyl benzene to improve on the mineral oil's properties was not uncommon.

Soon after, blends of AB and PAO became popular for retrofitting systems that had previously operated with naphthenic oils as the AB lessened elastomer shrinkage and helped dissolve system contaminants left behind by less stable lubricants (often naphthenic oils; Hytting 1999). Advantages of the synthetic include

- Longer life,
- Improved stability—when water and air are present,
- Reduced oil consumption—up to 70% reduction compared with mineral oils,
- Reduced and easier oil draining from the refrigeration plant, and
- Stable viscosity.

Additionally, the good dielectric properties of the ABs make their use in semi- hermetic ammonia refrigeration systems possible. Combinations of AB/PAO may also be suitable as the inclusion of the PAO may help reduce the pour point and slightly reduce water solubility, although these systems should be dry.

The low-temperature properties of these lubricants deserve further investigation. Pour point has most often been the single property used to determine how low a temperature at which the lubricant will flow. But this test considers the lubricant alone, not the ammonia environment. Additional tests, such as Scanning Brookfield Viscosity ASTM D 5133, measure the viscosity of the lubricant in centipoise (cP) versus temperature.

Table 2 compares the pour point, pour point under liquid ammonia, and the temperature at which each lubricant type reaches a nominal viscosity of 40,000 cP for several 68 ISO VG lubricants.

The ability of the PAO type to have improved flow at low temperatures is a result of lower viscosity. The optimized PAO continued to flow at lower temperatures and reached a viscosity of 100,000 cP at -53 °C (-63 °F). The results in the ammonia atmosphere seem to indicate that more solubility of ammonia is present in hydrocarbon lubricants than previously expected.

Pressure viscosity temperature (PVT) tests with ammonia have previously been reported for alkyl benzene ISO VG 68 (Seeton 2014). The report indicates that at 70°C (158 °F) and 30 bar (435 psi) ammonia is 6% mass soluble and would have a viscosity of about 3.7 cSt. An example for operation in a screw compressor might be at a lower pressure. The values used are not to suggest these pressures and temperatures are common or standard; rather they were selected to provide values easier to demonstrate results using the figures provided. At 15 bar (217 psi) and 67°C (153 °F) the solubility was much lower at 2%, resulting in a viscosity of about 8 cSt. The 2% dilution when cooled to about 42 °C (208 °F) reached 20 cSt, which would be suitable for lubricant supply to a screw compressor.

We tested both a Group II and a PAO ISO VG 68 with ammonia (see the results in Figures 1 and 2). For comparison with the alkyl benzene, the results show that at 70°C (158 °F) and 30 bar (435 psi), the Group II lubricant is about 5.2% mass soluble

Table 2. Low-temperature properties of selected lubricants.

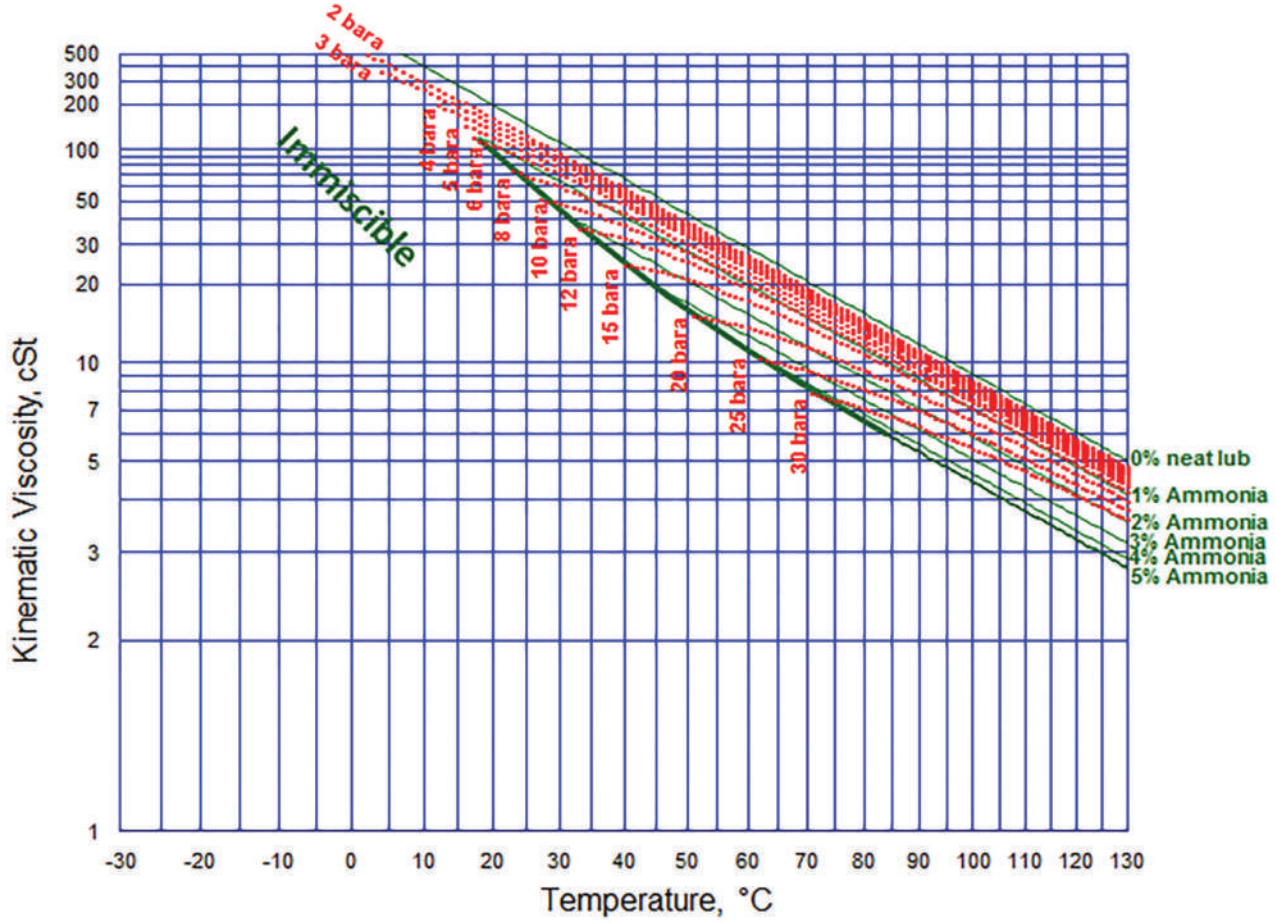
Lubricant Type	Pour point °C (°F)	Pour point ammonia atmosphere °C (°F)	Temperature for 40,000 cP °C (°F)
Group II formulated	-39 (-38)	-57 (-71) (a)	-32 (-26)
Group II/PAO formulated	-45 (-49)	n.a.	-35 (-31)
PAO	-48 (-54)	-54 (-65) (b)	-44 (-47)
PAO optimized	-64 (-83)	n.a.	-47 (-53)
PAO/AB optimized	-54 (-65)	n.a.	-37 (-35)
AB (c)	-40 (-40)	-51 (-60)	-22 (-8)

(a) Group II began to cloud up at -36 °C (-33°F), and laboratory personnel felt that some may have adhered to the glass.

(b) Some of the PAO may have stopped moving but was clear. But a noticeable film appeared at -54 °C (-65 °F).

(c) The alkyl benzene tested was not a true 68 ISO VG—it was 59 cSt at 40 °C (104 °F).

Figure 1. PVT chart for Group II ISO viscosity grade 68 with ammonia.



and would have a viscosity of about 8.09 cSt. At 15 bar (217 psi) and 67 °C (153°F), the solubility of the Group II lubricant was much lower at about 1.35% with a resulting viscosity of 14.4 cSt. This resulted in 33 cSt when cooled to 42°C. The PAO lubricant has a solubility of 4.1% mass at 70 °C (158 °F) and 30 bar (435 psi) and would have a viscosity of about 9.66 cSt. At 15 Bar (217 psi) and 67 °C (153 °F), the solubility of the PAO lubricant was much lower at about 1.48% and a viscosity of 15.6 cSt, this resulted in a viscosity of 35 cSt when cooled to 42°C. The results clearly indicate that the Group II and PAO lubricants result in slightly lower solubility and much higher operating viscosities under equivalent conditions when compared with the alkyl benzene. Also, the solubility of ammonia in these hydrocarbon type lubricants is clearly more than previous literature suggests.

MISCIBLE AND SOLUBLE LUBRICANTS FOR AMMONIA

The solubility and miscibility of hydrocarbon oil limits applications in systems with direct exchange (DX) evaporators. In the case of ammonia, normal naphthenic or paraffinic lubricants and synthetic hydrocarbon fluids/oils have low solubility and miscibility in ammonia. These oils are heavier than ammonia and tend to form an oil film, or "foul," on the heat transfer surfaces, which may decrease the system capacity and efficiency. The low solubility inherent with these oils also results in less dilution by the ammonia and a greater increase in refrigerant in direct expansion systems.

The oil film can become too thick for efficient heat transfer thereby contributing to excessive pressure increases in the evaporator and restricted oil return to the compressor.

Refrigeration systems with direct expansion (DX) evaporators have resulted in markedly reduced refrigerant charge (1/10th to 1/50th) when compared with that of conventional systems (Takahashi 2000). For example, welded plate and hybrid cross-flow plate evaporators have been proposed, which would provide significant reductions in required refrigerant volume for ammonia systems. The reduction in required refrigerant volumes allows for the achievement of efficient heat transfer while also reducing the potential for ammonia refrigerant leakage. The reduction in refrigerant charge volumes also enables ammonia to be safely permitted for use in a much wider variety of applications in addition to its common industrial applications. Further advantages of this type of system design include lower system cost and reduced system size and weight. However, to take full advantage of this type of evaporator system, using lubricants that have both a minimum effect on heat transfer efficiency and a minimum of pressure restriction in the evaporator would be desirable.

For more than 30 years, it has been known that certain PAG lubricants are soluble with ammonia. Increasing the ethylene content in PAGs increases miscibility with both ammonia and water. Because ammonia systems often contain water, this could be a problem. PAG copolymers of ethylene and propylene have inverse solubility with water. Keeping compressor discharge temperatures at 70 °C or higher can help prevent water accumulation. Above this temperature, the hotter the lubricant becomes, the less soluble water becomes. Below 70 °C water is completely soluble in the lubricant. Using the same concept with the fully capped PAG lubricants can further limit water solubility. A restriction of the use of PAG lubricants is that the ammonia miscible varieties have very low solubility with hydrocarbon oils. Compressors and systems must be flushed to remove any mineral oil that may be present. Oil-soluble PAGs are available that are soluble with ammonia. However, these types are not miscible with ammonia.

Note the difference between the meaning of soluble and miscible in the context of ammonia-compatible lubricants: Soluble refers to the ability of the ammonia gas to dissolve in the oil. Miscible refers to the ability of the ammonia liquid to mix completely with the lubricant. Certain varieties of ammonia-soluble lubricants, with limited miscibility, have been used with DX evaporators as the ammonia reduces their viscosity. Ammonia-soluble lubricants may offer advantages in respect to refrigeration plant operating costs through improved heat transfer efficiency due to the lower viscosity of the oil in the evaporator.

The PVT for a miscible PAG ISO VG 68 was investigated (see Figure 3). For comparison, the solubility and viscosity values were investigated at the same temperatures and pressures as provided for the immiscible lubricants. The results show that at 70 °C (158 °F) and 30 bar (435 psi) this PAG lubricant is about 25.6% mass soluble and would have a viscosity of about 2.3 cSt. At 15 bar (217 psi) and 67 °C (153 °F) the solubility of this lubricant is lower, but still significant, at about 10.9% with a resulting viscosity of 6.95 cSt. This resulted in 12.95 cSt when cooled to 42 °C (207.6 °F).

The PAGs benefit from a higher viscosity index. The 68 ISO VG described has a VI of 175. Producing PAGs with much higher VI is possible; however, this formula was optimized with higher miscibility as a first goal and viscometrics as a second goal. Miscibility was achieved to -55°C (-67°F).

If the 15 bar (217 psi) case were considered for the screw compressor, the discharge viscosity at 67 °C (153 °F) would be about 1 cSt lower than the alkyl benzene studied, and the lubricant supply viscosity at 42 °C (207.6 °F) would be about 8 cSt lower than the alkyl benzene. This is due to the higher solubility of ammonia in the PAG. The result is that an OEM requiring >12 cSt at the lubricant supply could use this ISO VG PAG, and an OEM requiring 20 cSt would require a higher ISO VG.

LUBRICITY

The lubricity requirements for lubricants used in ammonia compressors are relatively easy to satisfy when using the less soluble types of lubricants. Group II, PAO, and soluble lubricants have less wear in tests when compared with naphthenic mineral oil using Falex with steel pin and blocks in an ammonia atmosphere (O'Neill and Rajewski 1994). Other tests show that soluble/miscible type lubricants can have good lubricity without additives (Takahashi 2000).

ADDITIVES

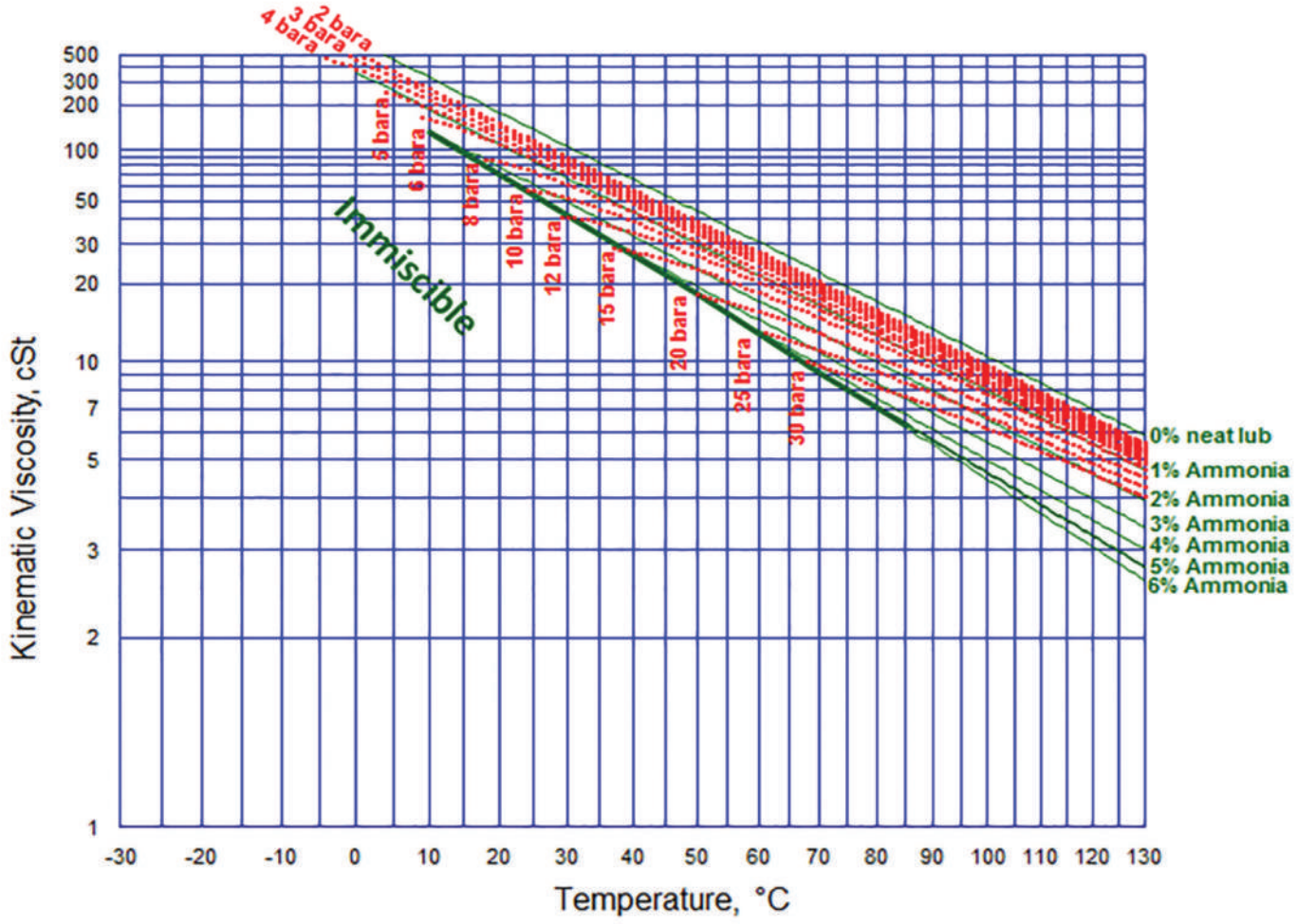
Several types of additives have been used in ammonia refrigeration compres-

sor lubricants. These include thermal and oxidation inhibitors, corrosion inhibitors, foam control, and viscosity index (VI) improvers (Rajewski and Lilje 2000). Metal passivators may also improve long-term stability. The VI improvers should be highly shear stable if the lubricant is to be used in screw compressors, as such it is not uncommon for a high-viscosity PAO to be used for this purpose. Pour point additives can significantly lower the pour point of a mineral oil. Paraffinic mineral oils almost always require a pour point additive as even the Group III type have pour points well above common evaporator temperatures for ammonia systems. If very high loads, sliding conditions, or other conditions that may lead to abrasion or excessive wearare indicated, then additives to improve lubricity may be included. Any additive used should be extensively tested with ammonia to confirm long-term compatibility and cleanliness. Test should include additions of common contaminants such as air and water and be in the presence of materials of construction.

Base fluids such as extremely highly refined Group II and Group III mineral oils and PAOs often have the tendency to shrink certain elastomers. To counteract this, alkyl benzene has historically been blended into these fluids. The addition of AB also assists the lubricant in solubilizing system contaminants that may otherwise deposit, causing lubrication and heat transfer issues. This property has also made such combinations of base stocks popular for retrofitting compressors previously using naphthenic oils.

Novel types of seal conditioners have been developed (Rajewski, Tolfa and Li 2004). A possible drawback of these additives is a potential to result in increased water absorption in the lubricant due to a hydroxyl end group. To overcome this, a further modification was made to remove the hydroxyl group and replace it with a hydrocarbon (Short 2009). This material, A508, demonstrated seal compatibility as shown in Table 3 where HT was a Group II mineral oil.

Figure 2. PVT chart for PAO ISO viscosity grade 68 with ammonia.



Interestingly, both seal conditioners described have also been used as the base fluid in ammonia-soluble compressor lubricants, even though they have low ammonia miscibility.

CO_2 COMPRESSOR LUBRICANTS

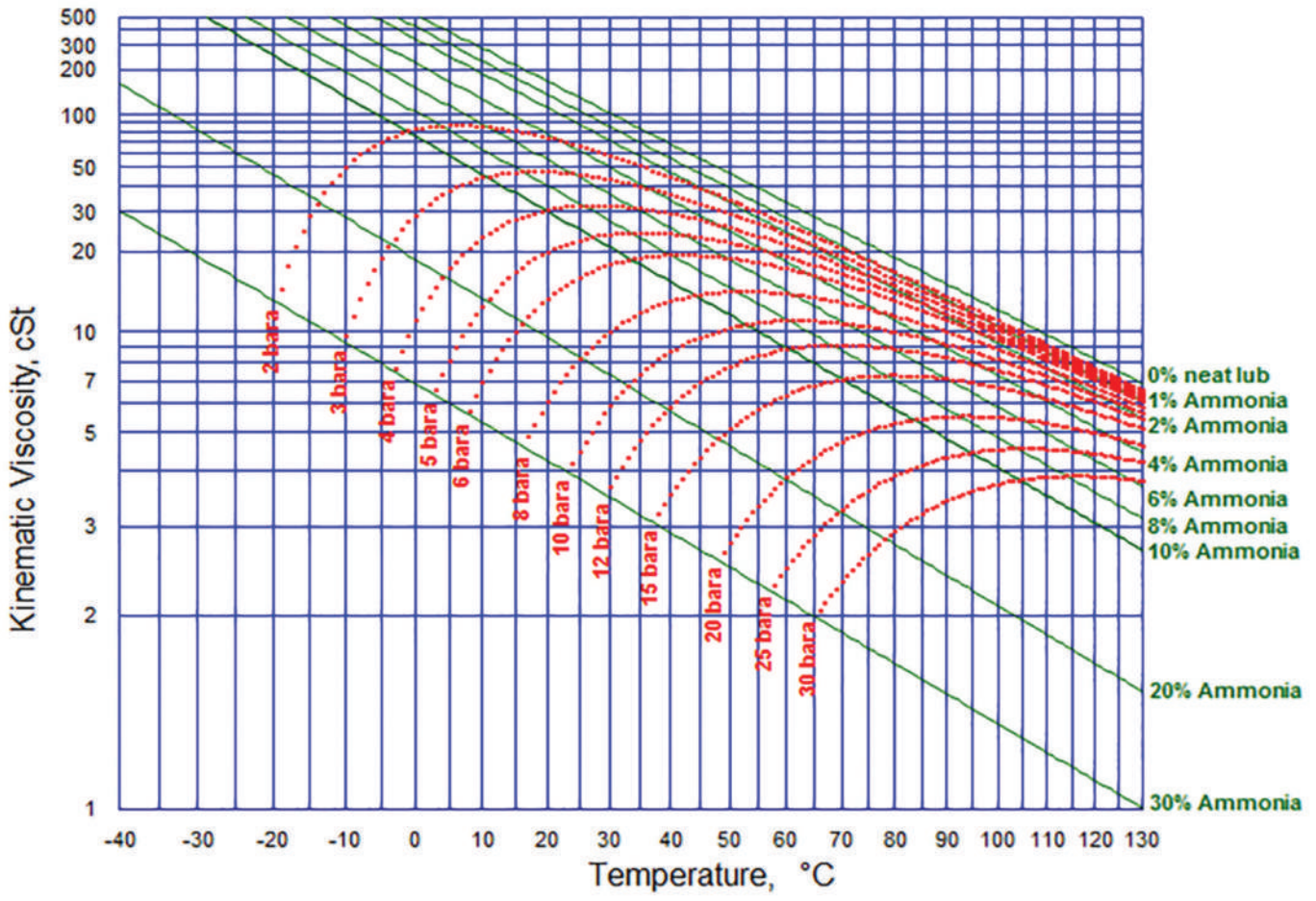
The lubrication requirements for CO_2 (R744) based equipment are different from equipment using other refrigerants such as ammonia or hydrofluorocarbon (HFC) refrigerants. This is due both to the higher system operating pressures of transcritical (or supercritical) CO_2 applications and the solubility of CO_2 with the different types of lubricants due to their molecular structures. The lubricant must be designed with a balance of properties to offer sufficient viscosity for lubricity and sealing, provide suitable miscibility with CO_2 for good lubricant return to the compressor, and promote overall efficiency of the refrigeration cycle. Some considerations are

- Compressor
  - Suitable mixture viscosity,
  - Lubricity under extreme pressure,
  - Stability under supercritical condition, and
  - Stability under high temperature
- Low-temperature side
  - Miscibility?
- Entire system
  - Compatibility with various materials.

The requirements for lubricants can also vary depending on the application. Transcritical CO_2 systems require a lubricant with miscibility, where subcritical CO_2 systems do not require a lubricant with high miscibility. Transcritical systems benefit more from a lubricant that maintains a higher working viscosity and may require a lubricant with an initial higher viscosity. Lubricants that resist dilution more may suffer from lack of miscibility.

Polyalphaolefin oils are less soluble with CO_2, but are also nearly completely immiscible. The low solubility makes the PAO easier to separate and with the correct

Figure 3. PVT chart for miscible PAG ISO viscosity grade 68 with ammonia.



system components, PAO can be used in both subcritical and transcritical applications. It has been suggested that multistage coalescing filters and active carbon filters may be required for use in transcritical applications. Any immiscible lubricant that must be drained from a low-temperature receiver may present a difficult challenge for oil separation and return as the lubricant is lower in density than liquid CO_2. Thus, a potential exists for long-term accumulation in evaporators.

Polyalkylene glycols (PAG) have excellent stability with CO_2, excellent hydrolytic stability, and good lubricity. They are hygroscopic and so tend to accumulate water. Their miscibility with CO_2 is not complete, and so they have inferior oil return compared with some other lubricants. Modified polyalkylene glycol (PAG) chemistry, generally double-end capped (fully capped), can be used to improve miscibility and control solubility with CO_2. A higher viscosity index of PAGs can provide superior lubrication with or without the inclusion of additives. The main structure of PAGs results in good stability and little or no hydrolysis. PAGs have also been found to be nonreactive with any carbonic acid formed by reaction of CO_2 with water. Fully capping leads to good lubricity and solubility and flexibility of controlling miscibility (Kaneko et al. 2004; Ikeda et al. 2006). PAGs have more water solubility than the other options; however, fully capping can somewhat reduce this solubility. Generally, even the fully capped PAGs will absorb a few thousand ppm water and so may not be acceptable for semi-hermetic or hermetic compressors due to the resulting reduction in dielectric strength.

The type of polyol ester oils (POE) that are used with HFC refrigerants are considered to have excessive solubility with CO_2. Fortunately, many chemistries are available for POEs that allow their customization to result in good miscibility and higher viscosity indexes and offer a wide range of viscosity grades. Antiwear additives are normally required. The potential negative of this type of lubricant is relatively poor hydrolytic stability, which makes keeping the lubricant and system free of moisture very important. Generously dimensioned molecular sieves have been proposed.

Polyvinyl ether (PVE) lubricants have good thermal, chemical, and hydrolytic stability and have good lubricity and dielectric strength. They may be more hygroscopic than POEs. PVE has high solubility and is generally considered miscible with CO_2. PVEs have a much lower viscosity index than PAGs and generally lower than most of the POEs currently being used in CO_2 applications. This means that for a given ISO viscosity grade, their viscosity at higher temperatures is lower. Development has continued toward a PAG/PVE copolymer oil for CO_2 heat pumps to retain the good stability and lubricity of PAG oil while having better viscosity characteristic than PVE (Kaneko et al. 2008). The cost of PVE lubricants also remains higher than the other lubricants currently being used.

MISCIBILITY OF LUBRICANTS FOR CO_2

In refrigeration systems with oil reservoirs, flooded evaporators, etc., to ensure good oil return to the compressor, the refrigerant oil must have either a higher density than the CO_2 refrigerant so that it can be drained from the reservoir, or good miscibility.

Table 4 presents a general consensus of the miscibility of several lubricants as reported in literature. Of these, only POE, polycarbonate, and PVE types have been described as miscible. In general terms, this miscibility is not complete through all temperatures, as even the miscible lubricants have ranges of immiscibility in areas of low concentration in the CO_2 at higher temperatures.

As Figure 4 shows carbon dioxide changes density very rapidly with temperature. PVE is not seen on this chart; however, it is expected to be similar to PAG. Similar charts have been published since 2000 (Hagita 2000 et al), This can result in a poorly miscible lubricant floating on top of the liquid refrigerant at some temperatures, while sinking to the bottom at other temperatures. This property is known as "phase inversion" and can be problematic in terms of oil separation. The density of the immiscible phase for the partly miscible lubricants will increase with increasing solubility of the CO_2. See Figure 5.

Fully miscible lubricants avoid this issue (Randles. Pasquin, and Gibb 2003). An oil rectifier can recover this oil from the low-temperature side (Christensen 2006). Immiscible lubricants require more elaborate systems. High-efficiency oil separation followed by a liquid separation system capable of collecting buoyant oil has been proposed (Gillies 2004). The system described was for a screw compressor with a primary coalescer element followed by secondary coalescer element with particle removal down to 0.01 micron to reduce the oil carry-over from compressors to less than 2 ppm. The liquid oil separator is installed in the liquid line from the condensers or possibly in the low-temperature pumped liquid line. Additional valves on the low- temperature vessel to allow future skimming of the liquid surface can be considered.

The miscibility of a 68 ISO VG fully capped PAG and a typical POE ISO VG 55 were investigated as shown in Figures 6 and 7. Note that pure lubricant is on the left, and pure CO_2 is on the right. The miscibility of the POE is good at lower temperatures.

The miscibility of the fully capped PAG is complete at higher concentrations of lubricant. However, it is immiscible when the lubricant concentration is slightly below 50%. Also, the concept of phase inversion is seen with the PAG.

The miscibility of PVE 68 has been reported and found to have a similar range of immiscibility as that of the POE reported here. The lowest temperature of immiscibility for PVE 68 was shown to be at about 10% lubricant concentration at 8 °C (46 °F; Seeton 2014). Additionally, a slightly more miscible POE ISO VG 68 was shown to be miscible at temperatures below 25 °C (77 °F). This lubricant was described as having good miscibility but experiences excessive viscosity reduction.

Modified types of fully capped PAGs have reported improved miscibility in low- lubricant concentrations. These also have an upper critical solution temperature that is consistent over a wide range of lubricant concentrations. A special

type of oil-soluble PAG has been tested for miscibility by the author and found to have a small miscibility range where the oil concentration is less than about 2%. This lubricant may be useful if oil concentrations reaching the evaporator can be limited. Of potential interest is that this oil-soluble lubricant has also been used with ammonia DX systems.

SOLUBILITY AND VISCOSITY OF LUBRICANTS FOR CO_2

Seeton and Hrnjak (2006) describe the apparatus for measuring the viscosity and composition of lubricant/CO_2 mixtures as a function of temperature and pressure. The POE and the fully capped PAG previously described have been tested using this method. In addition, an ISO VG 68 PAO was tested. See Figures 8, 9, and 10.

Most notable is the wide range of solubility among these three types of lubricants. For purposes of comparison, we will look at 50 bar (725 psi) CO_2 at two temperatures, 40 °C (104 °F) and 70 °C (158 °F) as these are easy to see in the figures. Table 5 shows the values.

The PAO viscosity benefits from lower solubility to maintain viscosity, while the FC PAG has less viscosity loss with dilution.

STABILITY

The thermal and oxidative stability of mineral oil with a phenolic oxidation inhibitor and uninhibited synthetic lubricant PAG, PAO, and POE have been studied pressurized to 2.76 MPa (27.6 bar, 400 psia) CO_2 using viscosity as an indicator of degradation at 100 °C over a period of six weeks (Weaver et al. 2013). The synthetic lubricants remained visually the same and had no reportable change in viscosity.

The mineral oil, however, turned black and began forming higher molecular weight species. Interestingly, this study was part of a report on the use of gas-expanded lubricants in tilting pad journal bearings with CO_2 used under pressure tunable mixtures wherein properties such as viscosity can be controlled directly in response to changing environmental or rotor dynamic conditions.

Stability in the presence of water is a concern for the more polar lubricants as these lubricants have a higher affinity to moisture. Water can react with CO_2 to form carbonic acid. Esters such as polyol esters are used extensively due to their excellent miscibility. These lubricants are known to cause concerns with hydrolytic stability. The presence of carbonic acid can accelerate their reaction with water.

Fully end-capped polyalkylene glycol lubricants have been preferred as they have less affinity for moisture and lack the terminal hydroxyl group of traditional PAGs that can react with carbonic acid (Randles Pasquin, and Gibb2003). However, PAGs with a hy-

Table 3. Test results with 100–105 psig (689–724 kPaG) ammonia, 200 °F (93 °C) for seven days.

Material (oil)	Elastomer	Swell change (mm)	Hardness Shore A (change)
HT-68 (96%) + 4% A508	BUNA N (70)	+0.001	62 (-8)
HT-68 (96%) + 4% A508	Neoprene (70)	+0.005	63 (-7)
PAO 4 (96%) + 4% A508	BUNA N (70)	+0.001	69 (-1)
PAO 4 (96%) + 4% A508	Neoprene (70)	+0.005	66 (-4)

Table 4. Overview of miscibility of CO_2 with a range of synthetic lubricants.

Lubricant	Miscibility
Alkyl benzene	Immiscible
PAO	Immiscible
Polyol esters	Miscible
PAG	Partially miscible
PVE	Miscible
Polycarbonates	Miscible

Figure 4. Change in density versus temperature for various 68 ISO VG lubricants.

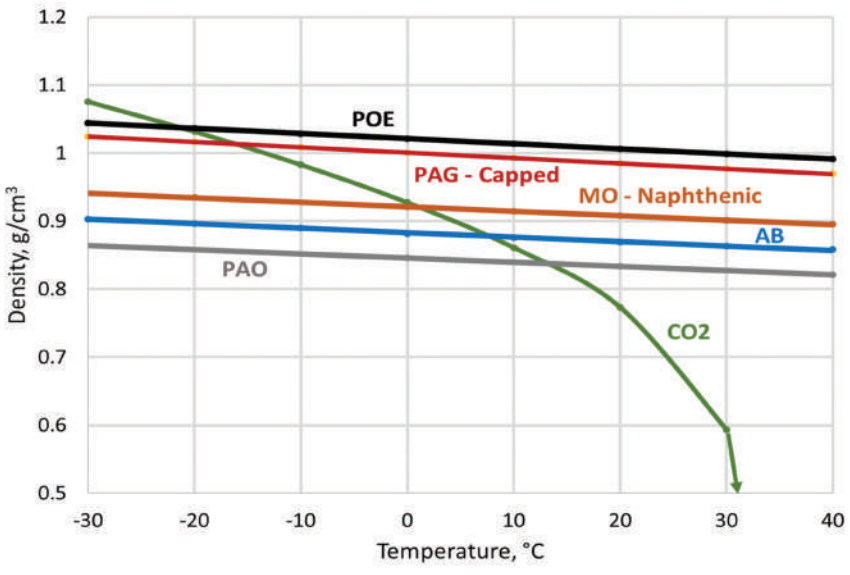
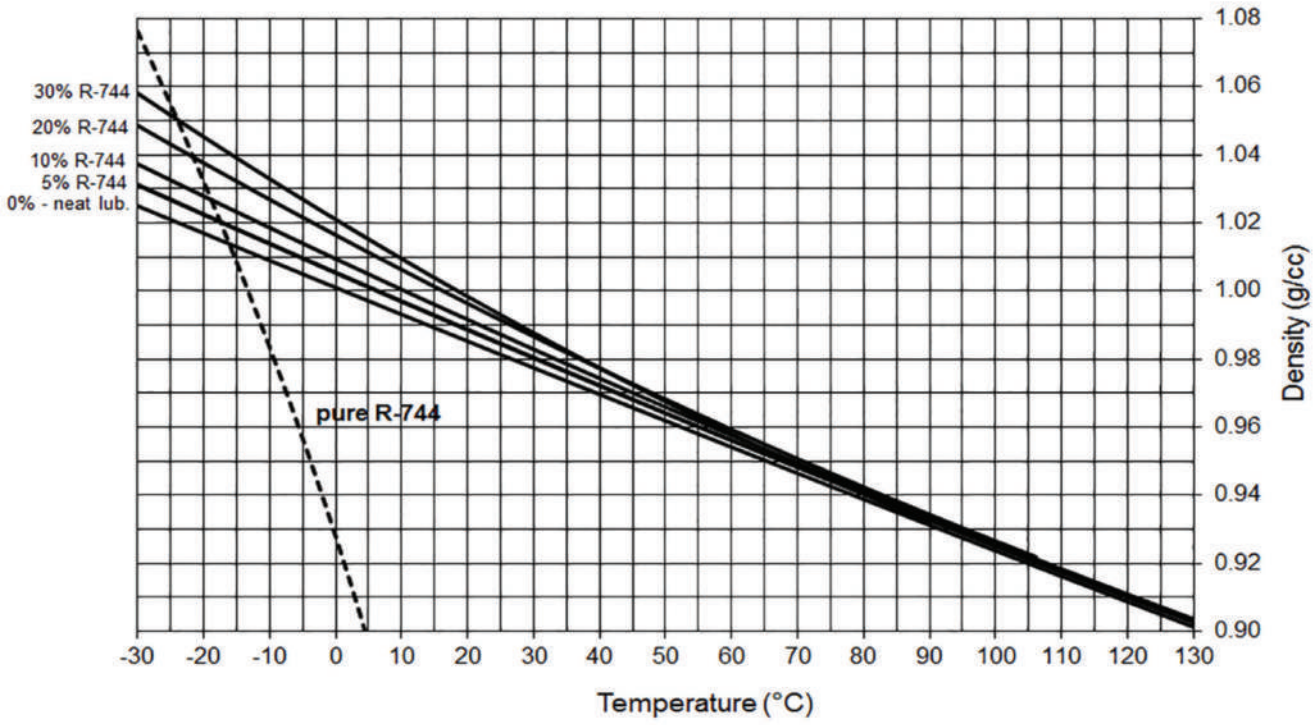


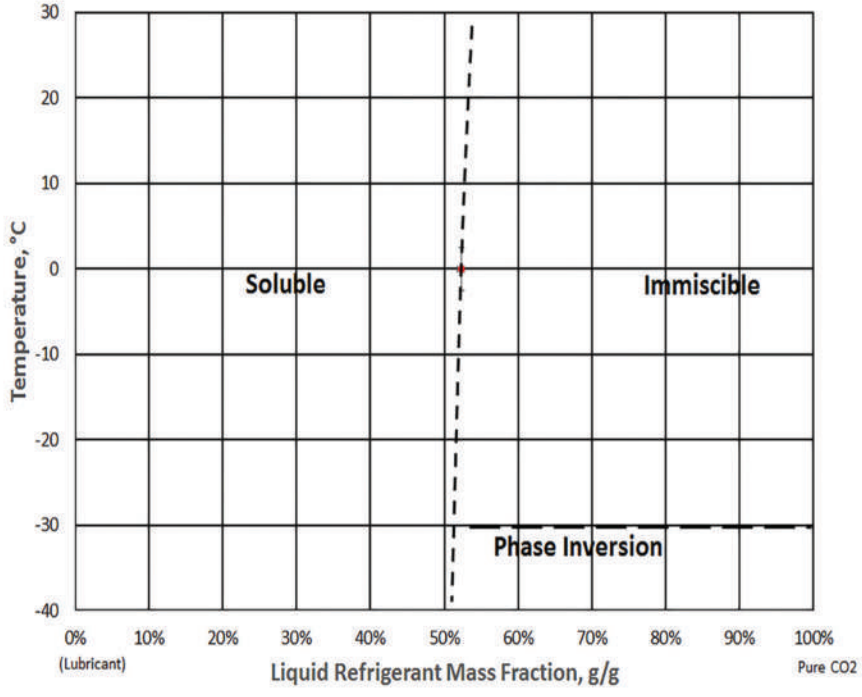
Figure 5. Density of a fully capped PAG ISO viscosity grade 68 with CO_2.



droxyl group were found to form small amounts of carbonates that may be beneficial for lubrication. The hydroxyl reacts with the CO_2 to form a carbonate that can act as a protective layer that improves tribological performance (Nunez , Demas, Polychronopoulou and Polycarpou 2008).

One study experimentally examined the stability and compatibility of several lubricants with CO_2 and typical compressor materials in construction such as iron, copper, and aluminum under high pressure and temperature conditions (Rohatgi and Spauschus Associates, Inc. 2010). The report found that mineral oils and alkyl benzene lubricants were most stable in CO_2, followed by polyalkylene glycols, and finally the least stable were polyol esters. Paraffinic mineral oils and alkyl benzene increased in total acid number less than traditional naphthenic mineral oils. Interestingly the conventional PAG showed a lower TAN increase

Figure 6. Miscibility of fully capped PAG ISO viscosity grade 68 with R744 (CO_2).



than the fully capped PAG, except when both the moisture level and the aging temperature were high. The more hydrolytically stable branched POE showed less TAN increase and resulted in less dissolved iron than the linear type POE. However, the report also concluded that aging temperature had a greater effect than moisture on the presence of dissolved iron in the aged POE lubricants. The similar structure of PAO to extremely highly refined mineral oils would lead to the expectation that the PAO would also be very stable, which has been observed over many years of commercial use.

LUBRICITY

Several studies have compared the lubricity of POE and PAG in CO_2 environments (Nunez et al. 2008; Kawaguchi and Boenninger 2004; Seeton et al. 2000; Ikeda et al.2004). In general, the ranking of lubricity is from better to worse:

PAG >PVE> POE

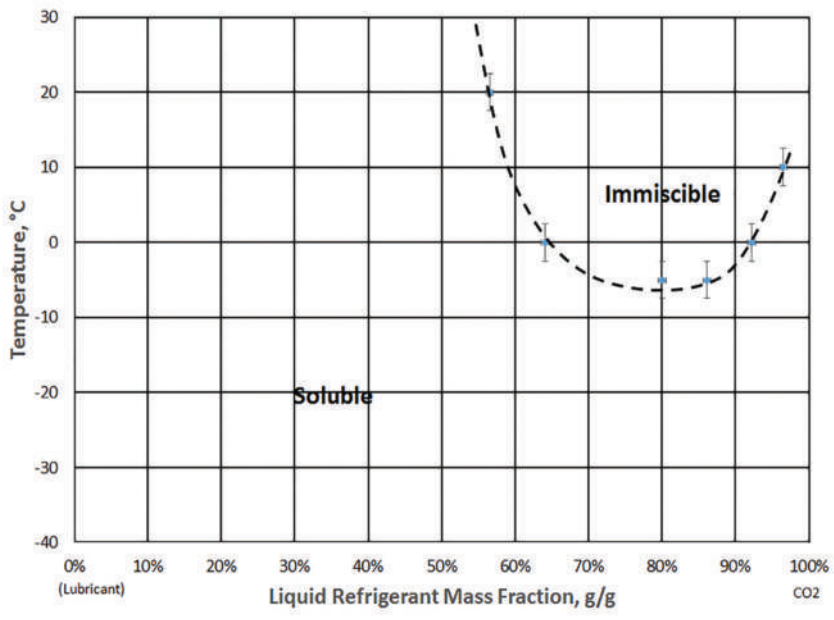
Tests have included high-pressure ball on disk, block wear, pin-on-disk, and Falex to simulate transcritical and supercritical conditions to observe wear and scuffing. Additives to reduce wear are commonly used to improve the performance of POEs and often included in PAG formulations.

ADDITIVES

Note that the degree and method of refining of these lubricants could highly influence stability and lubricity results as can other variables such as additives. Additives such as antioxidants, thermal stability improvers, corrosion inhibitors, and additives to improve lubricity are common for CO_2 compressor lubricant formulations and have been used for many decades for gas compressors and process applications. Traditional antiwear additives used in other compressor applications may be much more hydrolytically sensitive than the lubricant, therefore the formulation requires the use of more hydrolytically and thermally stable types. Copper deactivators can alleviate copper plating in systems where this is a potential issue.

Other additives may be used to reduce the effect of acids formed either from the thermal or oxidative breakdown of a polyol ester, or from water contamination. To test the stability of a polyol ester with and without such an additive, the samples were exposed to CO_2 and to CO_2 with water. Tests were performed in horizontal stainless steel cylinders for maximum surface area. All exposures were for 30 days at 130 °C (266 °F) at 34.47 barg (500 psig) with CO_2. Samples were tested with and without 1% water added. This would be an unusually large amount of water. The inhibitor had a positive effect as evidenced by measuring the TAN as reported in Table 6, where TAN is defined as Total Acid number as determined by titration of the sample with potasium hydroxide (KOH). Viscosity was also relatively unaffected. Note that the POE was also formulated with an antiwear additive that contributed to the initial acid number of the new sample. Because the acid number dropped when the inhibitor was formulated, it was later necessary to ensure the inhibitor underwent no loss of effectiveness.

Figure 7. Miscibility of POE ISO viscosity grade 55 with R744 (CO_2).



CONCERNS FOR CASCADE SYSTEMS

Refrigerants are chemicals, which creates a potential for reactions. Ammonia (R717) might be used as refrigerant in the high-temperature circuit in cascade systems with carbon dioxide (R744), and so a mixture of ammonia and carbon dioxide is then possible in case of a leak in the cascade heat exchanger. As the pressure on the R744 side of the cascade cooler is much higher than on the R717 side, a potential exists for contamination to take place on the R717 side. A mixture of carbon dioxide and ammonia can result in the formation of ammonium carbamate, which in a dry condition is a white powder and in an aqueous solution can be extremely corrosive.

Similarly, the designer should be aware that polyol esters and other esters used in CO_2 systems should not be allowed to contaminate R717 systems. Esters react with ammonia to form amides; these materials may occur as solids, viscous liquids, or sludge that may plug orifices, foul heat-transfer surfaces, and reduce overall system efficiency.

CONCLUSION

This paper aims to provide designers and operators with additional understanding of lubricants available for R717 and R744. Immiscible, soluble,

and miscible lubricants are currently available, and each type of lubricant has advantages and disadvantages. Just as in 1985 when the author introduced new lubricants for ammonia refrigeration applications (Short 1985), many opportunities for advances in synthetic lubricant technology to produce the optimum lubricant for any refrigerant application continue to exist.

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Figure 8. PVT chart for fully capped PAG ISO viscosity grade 68 with R744 (CO_2).

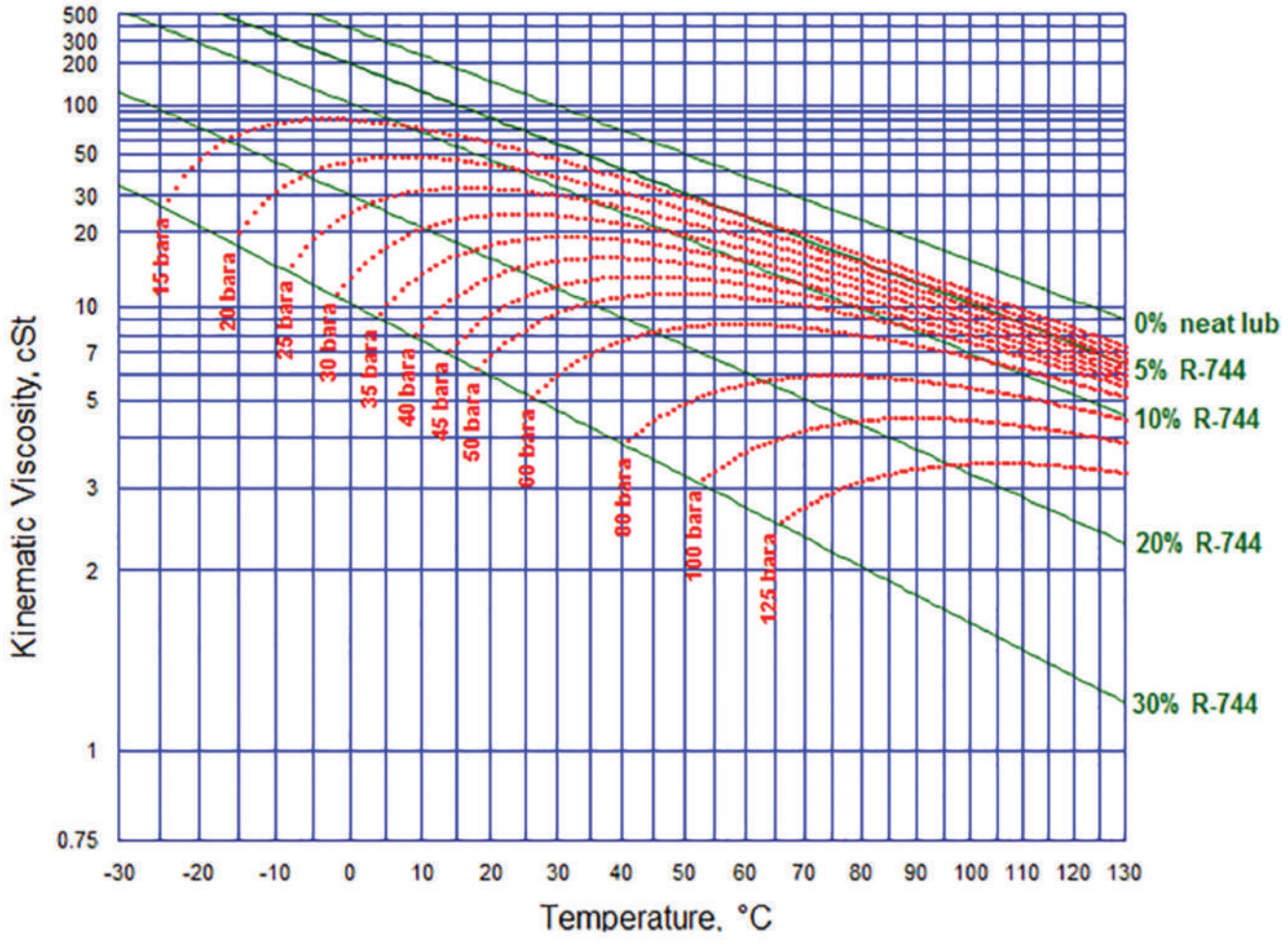

Figure 9. PVT chart for POE ISO viscosity grade 55 with R744 (CO_2).

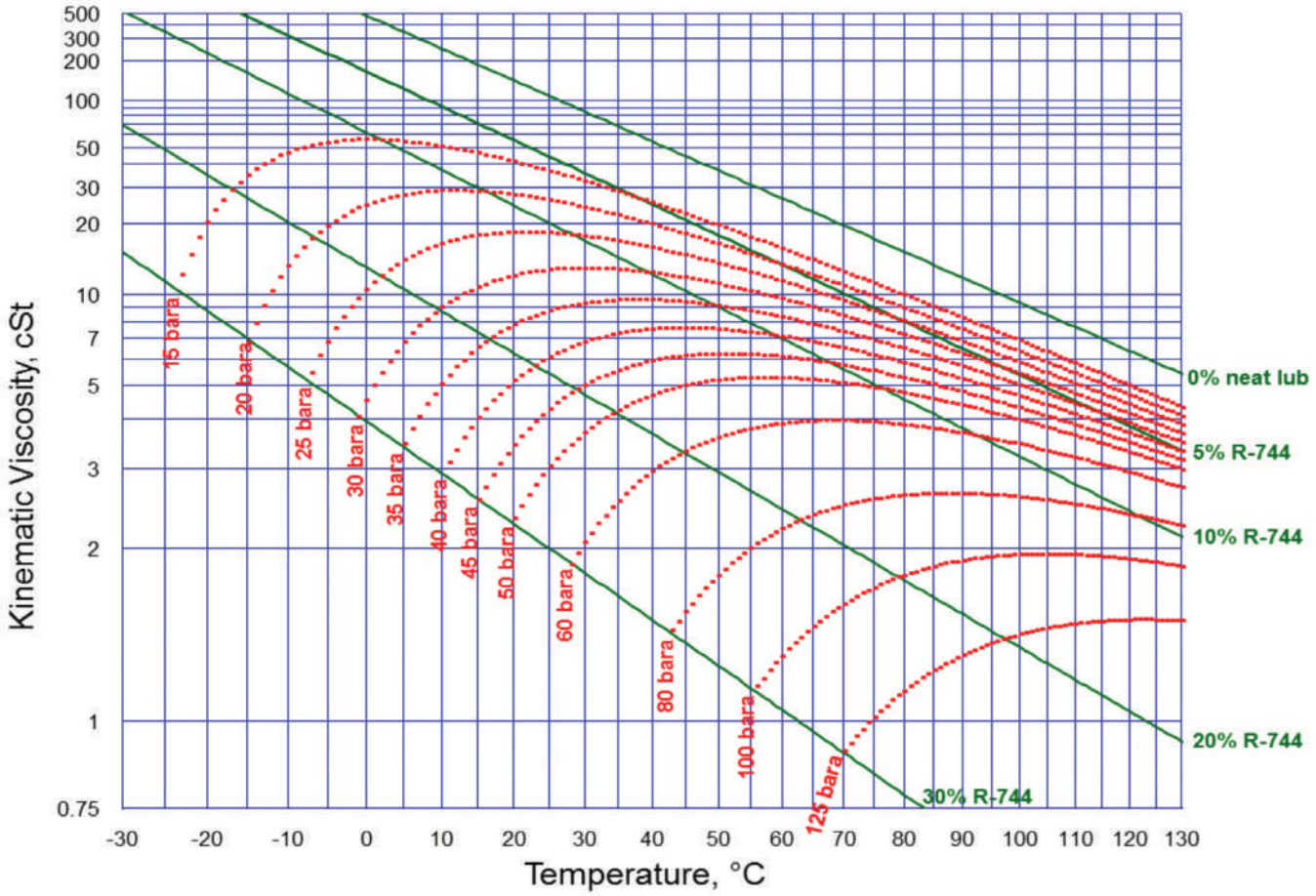

Table 5. Solubility and Viscosity Comparisons with CO_2

	50 bar (725 psi), 40 °C (104 °F)		50 bar (725 psi), 70 °C (158 °F)	
Lubricant	% mass CO_2	Viscosity, cSt	% mass CO_2	Viscosity, cSt
FC PAG ISO VG 68	18.13	11.00	11.85	10.19
POE ISO VG 55	17.68	4.70	10.81	5.09
PAO ISO VG 68	10.93	16.45	7.84	10.25

Figure 10. PVT chart for PAO ISO viscosity grade 68 with R744 (CO_2).

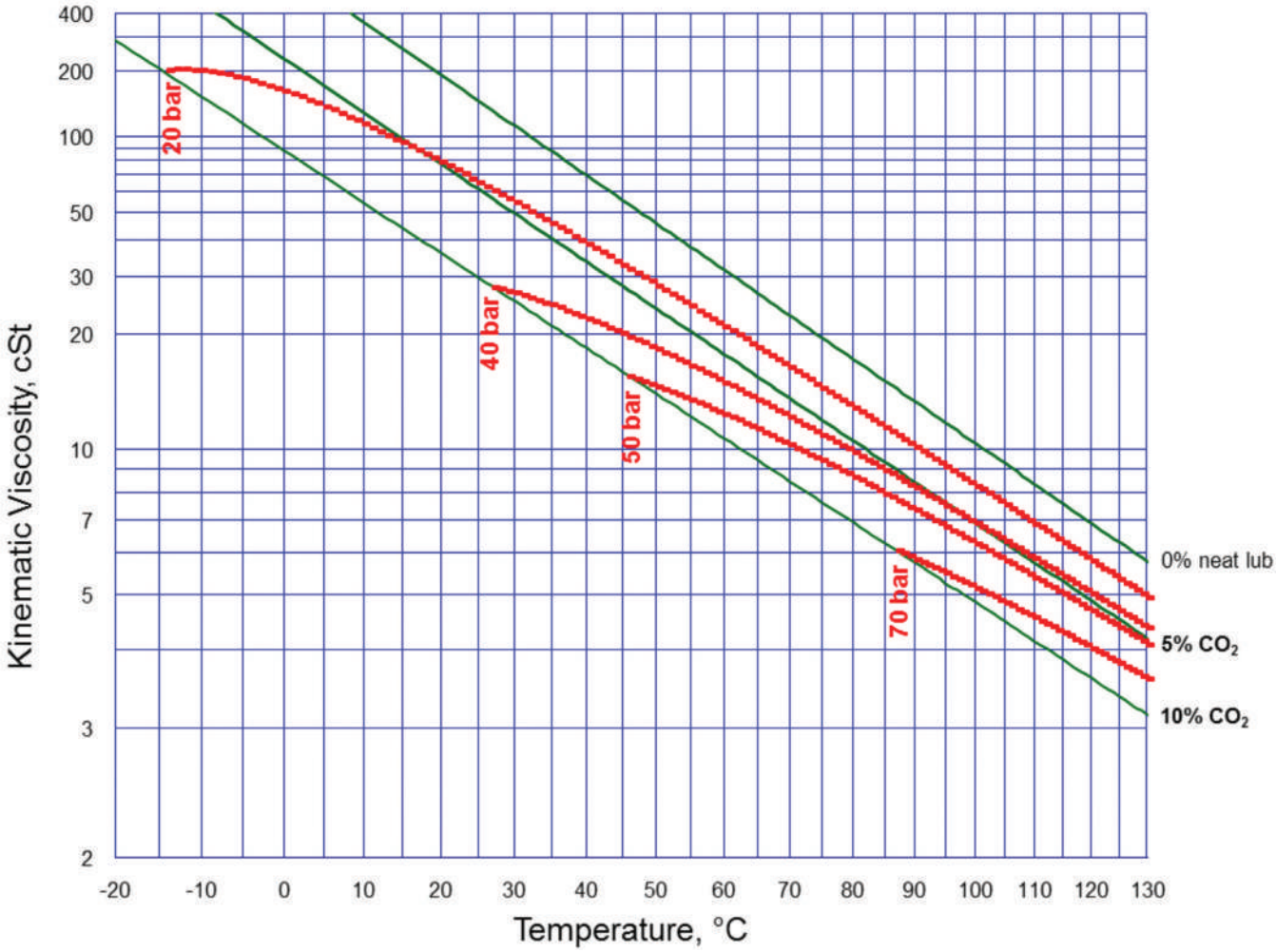

Table 6. TAN results after 30-day exposure to CO_2 with and without inhibitor.

	TAN (mg KOH/g of sample)		
Lubricant	New	After 30-day CO_2 exposure	After 30-day 1% H2O and CO_2 exposure
POE	0.19	0.80	17.64
POE with inhibitor	0.09	0.27	14.14

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