Safety Bulletin
Ammonia Refrigeration Safety

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Introduction

Ammonia refrigeration is a widely used industrial cooling system that operates on the principle of vapor compression refrigeration. It utilizes the unique properties of ammonia (NH3) as the refrigerant to transfer heat and provide cooling by compressing and condensing ammonia to create a high pressure and temperature stream. The key steps are listed below:

1. **Evaporation**: The process begins with liquid ammonia entering the evaporator at low pressure and temperature. As it flows through the evaporator coils, it absorbs heat from the surrounding environment (e.g., air or water) causing the ammonia to vaporize and turn into a gas.

2. **Compression:** The now gaseous ammonia is drawn into the compressor. Here, the compressor compresses the ammonia gas, significantly increasing its pressure and temperature. As a result, the ammonia exits the compressor as a high-pressure, high-temperature gas.

3. **Condensation**: The high-pressure, high-temperature ammonia gas then flows through the condenser coils, which are usually located outside or in a separate area. The surrounding environment (e.g., air or water) absorbs the heat from the ammonia, causing it to condense back into a high-pressure liquid state.

4. **Expansion**: The high-pressure liquid ammonia from the condenser moves into an expansion valve or throttle valve. The valve reduces the pressure of the ammonia, causing it to expand rapidly. As the ammonia expands, its temperature and pressure drop significantly.

5. **Return to Evaporator:** The low-pressure, low-temperature liquid ammonia is now in a state to re-enter the evaporator, and the cycle starts again. It absorbs heat from the surroundings, vaporizes into a gas, gets compressed, and condenses back into a liquid through each cycle.

In This Issue

This Safety Bulletin provides an overview of ammonia refrigeration, highlights some potential safety concerns with ammonia usage, reviews an industry incident, and fnisihes with recommendations of applicable Recognized and Generally Accepted Good Engineering Practices (RAGAGEP) for ammonia refrigeration systems.

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Ammonia is favored in industrial applications due to its excellent thermodynamic properties and high latent heat of vaporization, which allows it to transfer large amounts of heat efficiently. Additionally, it is environmentally friendly, with zero ozone depletion potential (ODP) and low global warming potential (GWP). However, ammonia is toxic, so safety measures and leak detection systems are crucial when using it as a refrigerant. Ammonia refrigeration systems pose a number of safety risks due to the corrosive and hazardous properties of ammonia along with the hazards associated with a system of varying temperatures, pressures, and state. General system design involves liquid, vapor, or mixed phase flow, temperatures ranging from -40°C - 45°C, and pressures up to 210 psig.

Properties at Standard Conditions (25°C, 1 atm):

Properties of Anhydrous Ammonia Vapor (25°C, 1 atm)[7]	
Density	0.699 kg/m^3
Boiling Point	-33.33°C
Specific Gravity	0.604
Flammability Range	15%-33%
Expansion Ratio	850

Ammonia refrigeration processes, while efficient and widely used in industrial applications, present several hazards due to the toxic and flammable nature of ammonia. These hazards require careful handling, proper maintenance, and strict adherence to safety protocols. Some of the significant hazards associated with ammonia refrigeration processes include:

1. **Toxicity:** Ammonia is highly toxic when inhaled or absorbed through the skin. Exposure to high concentrations of ammonia can cause respiratory issues, eye irritation, and skin burns. In extreme cases, it can lead to severe health problems and even death.

2. **Flammability:** Ammonia is flammable in specific concentrations in air (15% to 28% by volume). A flammable ammonia leak combined with an ignition source can result in fires or explosions, posing a significant risk to personnel and property.

3. **Pressure Hazards:** Ammonia refrigeration systems operate at high pressures, and any failure or rupture of equipment can lead to the release of high-pressure gas or liquid, causing dangerous situations.

4. **Asphyxiation:** Ammonia vapor displaces oxygen in the air. Leaks in confined spaces can lead to oxygen deficiency, potentially causing asphyxiation for personnel working in these areas.

5. **Environmental Impact:** While ammonia has low global warming potential (GWP), a large-scale release into the atmosphere can still have adverse effects on the environment and local ecosystems.

6. **Leak Detection and Response:** Ammonia leaks can be challenging to detect due to its colorless and odorless nature. Proper leak detection systems and protocols are essential to identify leaks promptly and initiate appropriate response actions to protect personnel and the environment.

7. **Chemical Incompatibility:** Ammonia can react with certain substances, such as chlorine-based cleaning agents or some metals, producing hazardous compounds or weakening equipment, leading to potential failure.

8. **Equipment Integrity and Maintenance:** Proper maintenance of ammonia refrigeration equipment is crucial to prevent leaks, pressure-related incidents, and other potential hazards. Corrosion, wear, and improper handling of equipment can lead to system failures.

To mitigate these hazards and ensure safe ammonia refrigeration processes, it is essential to implement rigorous safety measures, including personnel training, proper ventilation, protective equipment, leak detection systems, emergency response plans, and regular inspections and maintenance. Compliance with relevant safety standards and regulations is essential to reduce the risks associated with ammonia refrigeration systems effectively.

Additional Concerns include the following:

• Hydraulic Shock – Hydraulic shock occurs when high pressure liquid is sent through piping, generally due to liquid and vapor with a large temperature gradient inadvertently mixing.

• Frost – Due to cold temperatures at the evaporator coils, frost often forms in ammonia refrigeration systems. As a result, regular defrosting is required to ensure safe operation.

• Toxicity – Immediately Dangerous to Life and Health (IDLH) level of 300 ppm.

• As the density of anhydrous ammonia is less than that of air, the expectation is that it would rise and disperse; however, several factors can result in clouds of ammonia gas that linger at ground level. First, the reduced temperatures at the release site that result from the rapid depressurization and expansion upon release cause the gas to remain at a higher density longer. Additionally, as ammonia is highly hydrophilic, any moisture in the air will be absorbed and the resulting solution of vapor will have an increased density. It is important to understand the specific conditions that can impact the consequences of an ammonia release to ensure proper safe practices and adequate emergency response.

Figure 1: Example of Ammonia Release Spread[8]

the flammability range of ammonia is limited, there is still the potential for combustion. Additionally, there is potential for explosion if the correct concentration of ammonia in air is exposed to enough heat. The following chart provides the explosion temperature range for different concentrations of ammonia in air.

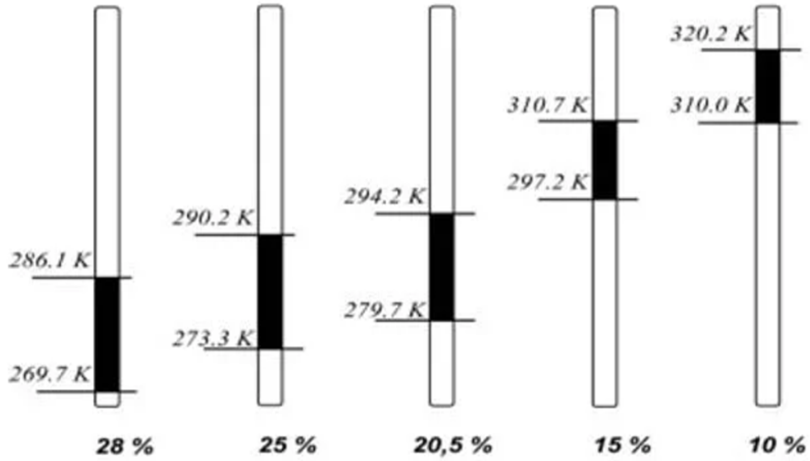

Figure 2: Explosion Temperature Range at Various Ammonia Concentration[1]

Previous Industry Event:
In 2010, a poultry facility with a 143,000 lb. ammonia refrigeration system released 32,00 lb. of ammonia to the environment after piping was damaged by hydraulic shock. [2]
Cause: Following a loss of power, during a response to alarms from the system, several evaporators that were defrosting were brought back online without first draining the hot vapor used for defrosting. When this occurred, a valve opened, allowing cold liquid ammonia to flow to the evaporator, leading to rapid condensation of the vapor and vacuum formation. This resulted in a high pressure liquid slug to be sent downstream where hydraulic shock led to the rupture of the evaporator piping manifold and rooftop piping. 32,000 lbs. of ammonia was released, creating a large vapor cloud. This release included the contents from 4 evaporator coils, as all 4 were tied to a single valve.[3]
Outcome: 153 offsite contractors required medical attention. 32 hospitalized. 4 requiring intensive care.
Suggestions:

- Avoid manual interruption of defrosting.
- Program controls to automatically remove the evaporator contents prior to refrigeration start-up.
- Design each coil in the evaporator to be controlled by separate sets of valves.[2]

Standards:
The most advised available RAGAGEP for safe design, operation, and emergency preparedness is the International Institute of Ammonia Refrigeration (IIAR) Ammonia Refrigeration Management (ARM) Program, which is comprised of IIAR 1-8.[5]
The following table presents other available standards related to ammonia refrigeration systems:

Standards for Ammonia Refrigeration Safety[5]

Institution and Standard Number	Standard Title or Contents
American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard 15 & 34.	*Safety Standard for Refrigeration Systems* & *Designation and Classification of Refrigerants*
Compressed Gas Association (CGA) G-2.1	*American National Standard Safety Requirements for the Storage and Handling of Anhydrous Ammonia*
U.S. EPA Region 7 guidance	*Accident Prevention and Response Manual for Anhydrous Ammonia Refrigeration System Operators*
American Society of Mechanical Engineers (ASME) B31.5	*Refrigeration Piping and Heat Transfer Components*

Safety Suggestions:

1. Establish a proper Mechanical Integrity Program as described in IIAR 6.
2. Defrost evaporators regularly and ensure procedures include proper draining of evaporators following defrost.
3. IIAR 2 suggests using dual pressure relief devices on a 3-way valve to allow for maintenance.
4. Utilize dual detection in the machinery rooms with an alarm at 25 ppm and liquid valve shutdown at 35 ppm.

References:

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