# MECHANICAL REFRIGERATION

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## 1.0 SCOPE

This data sheet provides recommendations for fire and explosion protection and prevention for (and protection against contamination from) industrial-type refrigeration equipment. Included are both nonflammable (chlorofluorocarbons or CFCs) and flammable (ammonia and light hydrocarbon) refrigerants. Package systems for comfort cooling are not included, although some of the design concepts could apply.

Refrigeration is a requirement in certain occupancies. However, the selection of refrigerant plays a significant role in defining the overall risk or exposure to the facility. Recent developments in the use of liquefied hydrocarbon gases, such as methane-based mixtures, isobutane, and propane present a much higher hazard.

### 1.1 Changes

January 2018. This document has been completely revised. Major changes include the following:

A. Recommendations for flammable refrigerants have been moved to a new section for better visibility.

B. Indirect systems are recommended for new construction when flammable refrigerant or ammonia is used.

C. Automatic emergency shutdown is recommended for locations where a flammable refrigerant or ammonia is used.

D. Refrigerant classifications have been updated to be consistent with international standards for refrigerant identification.

E. Recommendations related to critical piping and controls have been incorporated into DS 7-13 from DS 12-61.

F. Added recommendation for emergency ventilation controls located outside areas where refrigerant leaks may occur.

G. Added recommendation for areas where lower emergency ventilation rates are required to comply with local regulations.

H. Added recommendation for isolation valves at critical points in the system to minimize the amount of refrigerant released and facilitate drainage.

I. Updated recommendations on calibration frequency of ammonia or refrigerant detectors.

J. Updated human element recommendations to be consistent with DS 10-8 and DS 10-2.

K. Added recommendation for a formal, written contingency plan to address contamination remediation, isolation, rental equipment, and relocation of stock.

L. Updated loss history and illustrative losses.

### 1.2 Hazard

Refer to FM Understanding the Hazard (UTH) publication P0045, *Accidental Release of Ammonia*.

## 2.0 LOSS PREVENTION RECOMMENDATIONS

### 2.1 Introduction

2.1.1 Management of change. Evaluate properties of replacement refrigerants prior to charging any system. Such evaluation includes potential reaction between old and new refrigerants, and modifications needed to accommodate a refrigerant with a different flammability or toxicity profile than the one being replaced.

2.1.2 Use FM Approved equipment, materials, and services whenever they are applicable. For a list of products and services that are FM Approved, see the *Approval Guide*, an online resource of FM Approvals.

### 2.2 Flammability and Contamination

2.2.1 Use indirect refrigeration systems for flammability classification 2 or 3 refrigerants. Indirect refrigeration systems are preferred for ammonia because of the potential for contamination.

2.2.1.1 Locate piping and evaporators containing flammability classification 2L, 2, and 3 refrigerant outside of the building (except within the machinery room).

2.2.1.2 Where piping or evaporators containing flammability classification 2L, 2, or 3 refrigerant are required to be located in the building areas outside the machinery room, provide additional safeguards as specified for direct refrigeration systems in 2.2.2.

2.2.1.3 Provide an accessible manual control to activate the emergency shutdown system if the automatic system fails. Locate the manual control outside the machinery room or in accordance with local building codes or regulations.

2.2.2 Direct refrigeration systems are acceptable for ammonia and other flammability classification 2L where additional safeguards are provided as follows.

2.2.2.1 Locate piping containing ammonia or other flammability classification 2L refrigerant outside of the building as much as possible.

2.2.2.2 Provide an emergency shutdown system arranged to automatically close all liquid isolation valves upstream of the associated accumulators and/or receivers and evaporator coil units. When a leak is detected in the refrigerated area, the liquid isolation valves should close but the compressor should continue to operate so the ammonia returns to the machinery room and the volume leaked into the refrigerated space is minimized.

2.2.2.3 Where the leak is detected in a refrigerated area that can be physically isolated to prevent refrigerant migration, it is acceptable to close only the liquid isolation valves in the affected area.

2.2.2.4 Activate the emergency shutdown system automatically upon refrigerant detection. Set refrigerant detectors in the refrigerated area to alarm and shutdown the refrigeration system at levels no greater than 400 ppm.

2.2.2.5 Provide an accessible manual control to activate the emergency shutdown system if the automatic system fails. Locate the manual control immediately outside the machinery room or in accordance with local building codes or regulations.

2.2.2.6 Ensure detector spacing and location are in accordance with manufacturer's guidelines or in the vicinity of any evaporators. Consider the potential leak points and airflow patterns.

2.2.2.7 Provide routine walk-through inspections of normally unattended areas to identify small leaks that fall below the detector set-point.

2.2.2.8 In seismically active areas, perform a hazard evaluation to identify system vulnerabilities related to susceptibility to damage from earth movement events. Provide mitigation in accordance with Data Sheet 1-2 as applicable.

### 2.3 Construction and Location

2.3.1 Provide a detached building for machinery rooms where flammability classification 2 or 3 refrigerants are used.

2.3.2 Locate indoor equipment using flammability classification 2L refrigerants as follows (in order of decreasing desirability):

A. Detached building or a building limited to equipment for central utility systems

B. Peninsular part of building being served with three exterior walls, an exposed roof, and a remote location with respect to business offices and other non-industrial areas

C. Along the exterior of building served, having one or two exterior walls, an exterior roof, and a remote location with respect to business offices and other non-industrial areas

2.3.3 Do not locate equipment using flammability classification 2L, 2, or 3 refrigerants in basements.

2.3.4 Equipment using flammability classification 1 refrigerants can be located in any properly arranged cutoff area.

2.3.5 Construct machinery rooms of noncombustible or fire-resistant materials.

2.3.6 Ensure walls common to other occupancies are vapor tight.

2.3.7 Ensure machinery rooms for flammability classification 2 or 3 refrigerants have 1-hour fire-rated walls.

2.3.8 Ensure machinery rooms for flammability classification 2 and 3 refrigerants are of damage-limiting construction (DLC) in accordance with Data Sheet 1-44, *Damage-Limiting Construction*.

2.3.9 Ensure machinery rooms for ammonia and other flammability classification 2L refrigerants are constructed to mitigate the overpressure related to a release using one of the following methods (listed in order of preference):

A. Damage-limiting construction in accordance with DS 1-44.

B. Lightweight insulated metal panels on exterior walls that can release in the event of an overpressure event.

C. In cases where the machinery room will not have any exterior walls, ensure the available charge in the machinery room is minimized, detectors are installed and regularly calibrated, and automatic shutdown systems are installed and arranged to electrically isolate the machinery room.

2.3.10 Do not locate accumulators and receivers on the roof unless they are independently supported.

2.3.11 Ensure existing structures are capable of accommodating additional static load where new equipment is to be installed. Specifically, evaluate the impact of new or replacement equipment on the availability of the structural live load.

2.3.12 Ensure doors to adjoining occupancies are tight, self-closing, and with a fire rating equivalent to the wall. Ensure doors in pressure-resistive walls have equal pressure resistance.

2.3.13 Protect pipe penetrations through interior walls with FM Approved fire stops with a fire protection rating equal to or greater than the wall rating. FM Approved fire stops should be installed by an FM Approved fire stop contractor.

2.3.14 Ensure construction and protection in refrigerated areas are in accordance with Data Sheet 8-9, *Storage of Class 1, 2, 3, 4, and Plastic Commodities* and Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*.

2.3.15 Arrange fans (exhaust, evaporator, and circulation) so they do not interfere with sprinkler operation (see Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers)*.

### 2.4 Equipment and Processes

#### 2.4.1 Piping and Controls

2.4.1.1 Ensure piping and fittings comply with ANSI Standard B31.5, *Refrigeration Piping and Heat Transfer Components*, or equivalent local standard. For ammonia refrigeration systems, ensure piping and fittings comply with IIAR 2, *Standard for Safe Design of Closed-Circuit Ammonia Refrigeration Systems*, and specifically do not use cast iron or copper-based alloy for piping or joints.

2.4.1.2 Ensure refrigerant piping is clearly labeled (color coded) as to service and contents when flammability classification 2L, 2, and 3 refrigerants are used. In addition, mark piping with the direction of flow of both liquid and gaseous refrigerant.

2.4.1.3 Seal weld or braze all threaded joints used with flammability classification 2 or 3 refrigerants.

2.4.1.4 Use welded pipe and fittings on pipe larger than 1 in. NPS (25.4 mm) when used for flammability classification 2L, 2, or 3 refrigerants.

2.4.1.5 Protect piping from mechanical damage, including impact from forklifts, lift trucks, automated equipment, and personnel (see Figures 1 and 2).

2.4.1.6 Properly support piping with minimum hanger size and spacing as indicated in Table 1. Where unusually high loads might be placed on the piping (e.g., risers extending for long runs over multiple stories and systems with expansion joints for pipe over 3 in. [76 mm] diameter), have a qualified engineer design or review the pipe supports. Ensure short sections of drain piping on receivers with valves or other weighty devices are properly supported.

*Fig. 1. Refrigerant piping*

*Fig. 2. Refrigeration unit*

*Table 1. Design of Pipe Supports (Adapted from IIAR 2 and MSS SP 58)*

| *Nominal Pipe Size, Standard Weight Steel Pipe, Liquid Filled*[1] | | *Maximum Span* | | *Minimum Rod Diameter* | |
|---|---|---|---|---|---|
| in. | cm | ft | m | in. | cm |
| ≤1 | 2.5 | 7 | 2.1 | 3/8 | 0.95 |
| 1½ | 3.8 | 9 | 2.7 | 3/8 | 0.95 |
| 2 | 5.1 | 10 | 3.1 | 3/8 | 0.95 |
| 2½ | 6.4 | 11 | 3.4 | ½ | 1.27 |
| 3 | 7.6 | 12 | 3.7 | ½ | 1.27 |
| 4 | 10.1 | 14 | 4.3 | 5/8 | 1.59 |
| 5 | 12.7 | 16 | 4.8 | 5/8 | 1.59 |
| 6 | 15.2 | 17 | 5.2 | ¾ | 1.91 |
| 8 | 20.3 | 19 | 5.8 | 7/8 | 2.22 |
| 10 | 25.4 | 22 | 6.7 | 7/8 | 2.22 |
| 12 | 30.5 | 23 | 7.0 | 7/8 | 2.22 |
| 14 | 35.6 | 25 | 7.5 | 1 | 2.54 |
| 16 | 40.6 | 27 | 8.1 | 1 | 2.54 |
| 18 | 45.7 | 28 | 8.4 | 1¼ | 3.18 |
| 20 | 50.8 | 30 | 9.0 | 1¼ | 3.18 |

[1] The dimensions apply to standard weight steel pipe with ASTM A36 threaded steel rods or equivalent and do not consider seismic, thermal, or other dynamic loads.

2.4.1.7 Provide sleeves for all refrigerant piping passing through walls or floors to protect from abrasion, and provide a means for inspection.

### 2.4.2 Insulation

2.4.2.1 Protect refrigerant piping against external corrosion.

2.4.2.2 Insulate refrigerant vapor piping downstream of the evaporator to prevent internal condensation and liquid slugging.

2.4.2.3 Use noncombustible, non-absorbent pipe insulation (e.g., cellular glass) that is tight-fitting. Non-absorbent insulation is recommended to minimize the potential for off-gassing following a release, complicating mitigation efforts. Noncombustible insulation is recommended to limit the potential for fire spread.

2.4.2.4 Where gauge glasses are used to indicate liquid levels in receivers, accumulators, purgers, etc. (see Figure 3), or other suitable protection, provide armored-type gauge glasses. Equip gauge glasses with automatic flow check devices to minimize refrigerant loss in the event of glass breakage.


*Fig. 3. Typical armored gauge glass assembly*

2.4.2.5 Install a pressure-limiting device, actuated directly by the pressure in the system, to shut down the compressor(s) in the event of excessive pressure. Set the device to act below the threshold pressures of system relief valves to prevent loss of refrigerant.

2.4.2.6 Equip accumulators and inter-stage coolers with high refrigerant level float switches arranged to sound an alarm and, where feasible, remove the compressors from service to protect positive displacement compressors from liquid entry and subsequent slugging damage. In addition, provide the following minimum safety controls:

- Low-pressure cutout switch
- High-pressure cutout switch
- Low-differential oil pressure cutout switch

### 2.4.3 Pressure Relief

2.4.3.1 Provide a relief valve vented to a safe outdoor location on all receivers, shell-type condensers, shell-type glycol coolers, evaporators, and generators. Do not install controlling valves on the vent pipe.

2.4.3.2 Provide dual relief valves on receivers where flammability classification 2L, 2, or 3 refrigerants are used so a relief valve can be removed without draining all liquid from the vessel.

2.4.3.3 Provide a defrost controller designed to sequentially operate the logical defrost steps (pump-out, hot gas, equalize, and fan delay) to prevent liquid accumulations in the evaporator coils.

2.4.3.3.1 Depending on system design, float drainers may also be needed at the ends or at trapped areas of hot gas lines to drain off condensed liquid and oil into the return or suction lines.

2.4.3.4 Locate all critical valves that can be used to isolate the flow of liquid refrigerant and all hot gas to the plant so as to be readily accessible from the floor level (direct or chain) or from access platforms.

A. Install shut-off and/or isolation valves at locations to minimize the amount of refrigerant released and facilitate draining of refrigerant when systems are shutdown following emergency.

1. The actual number of shut-off/isolation valves will vary depending on the piping system size, complexity, and the potential exposure created by a release.

2. Welded or flanged valves are preferred for all sizes; however, threaded valve bodies are acceptable for sizes 1.00 in. (2.54 cm) and smaller.

B. Label critical valves by attaching permanent, easily-readable tags.

C. Post a system drawing outside of the machinery room(s) and refrigerated spaces indicating the location of all critical valves. Identify the type(s) of refrigerant(s) in the system(s) on the drawing.

### 2.5 Occupancy

2.5.1 Do not locate boilers and other flame-producing equipment in the machinery room for any refrigerant (excluding $CO_2$).

2.5.2 Do not store lubricants or other combustible materials in the machinery room unless housed in an FM Approved ignitable liquid storage cabinet. See Data Sheet 7-32, *Ignitable Liquids Operations*, for further guidance.

2.5.3 Where the machinery room is within the envelope of the building being served, design the system to minimize the charge of ignitable liquid or liquefied flammable gas within the machinery room, such as by locating accumulators or receivers outside if feasible.

2.5.4 Ensure the following ventilation requirements are met in the machinery room:

A. For flammability classification 1 refrigerants, ventilation is needed only as required for equipment cooling or as required by local authorities for personnel comfort.

B. For flammability classification 2L refrigerants, provide continuous mechanical ventilation at a rate of at least 0.5 cfm/ft$^2$ (0.15 m$^3$/min/m$^2$).

C. For flammability classification 2 and 3 refrigerants, provide continuous mechanical ventilation at a rate of at least 1 cfm/ft$^2$ (0.3 m$^3$/min/m$^2$).

2.5.4.1 Locate intake louvers and the exhaust device (fan or roof openings) to promote mixing and avoid short circuiting of airflow, based on the vapor density of the refrigerant. Exhaust to outdoors, away from any other building intakes.

2.5.4.2 Power fans from a source separate from the machinery room so a shutdown of power to the room does not affect the fans.

2.5.5 If the machinery room is within the envelope of the building being served and flammability classification 2L, 2, or 3 refrigerant is used, provide an emergency ventilation system designed to vent directly to the outside.

A. Size ventilation system to provide at least 30 air changes per hour based on the gross machinery room volume.

B. Power fans from a source separate from the machinery room so a shutdown of power to the room does not affect the fans.

C. Initiate emergency ventilation at gas detection of not more than 1000 ppm.

2.5.6 Where local regulations require lower emergency ventilation rates or shutdown of emergency ventilation in the event of an ammonia release, do the following:

A. Inspect seals around pipe penetrations and any other wall openings regularly to prevent ammonia migration to refrigerated area(s) in the event of a release.

B. De-energize electrical equipment at ammonia detection levels not greater than 25% of LEL. Alternatively, provide FM Approved Class 1 Division 1 (Zone 1 or Zone 0) rated electrical equipment.

C. Promptly implement emergency response plan, including manual mitigation and cleanup methods (see 2.8.2 and Appendix C.4).

2.5.7 Locate ventilation system controls outside of the areas of risk to ensure ventilation and exhaust systems can operate in an emergency.

### 2.6 Protection

2.6.1 Install automatic sprinklers for the HC-2 occupancy in Data Sheet 3-26, *Fire Protection Water Demand for Nonstorage Sprinklered Properties*, in all machinery rooms.

2.6.2 For refrigeration compressors with large, force feed lubrication systems, see Data Sheet 7-95, *Compressors*, for guidance on mechanical integrity and fire protection issues.

2.6.3 For guidance on fire protection in refrigerated warehouses, see Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*.

### 2.7 Operation and Maintenance

2.7.1 Provide a comprehensive preventive maintenance program to reduce the chance of a leak or refrigerant release, as well as increase system availability and efficiency. Adhere closely to manufacturers' guidelines for maintenance.

2.7.2 Do not bypass any process safeguards when performing maintenance or inspections unless a documented lockout/tagout program is established and other means are provided to supervise the safeguard.

2.7.3 Inspect, calibrate, and/or test all instrumentation and controls on an annual basis. Document inspections and maintain records.

2.7.4 Have refrigerant detectors calibrated by qualified personnel at least quarterly or in accordance with manufacturer's instructions, whichever is shorter, for the first year of service. The calibration frequency can be extended to 6 months or in accordance with manufacturer's instructions, whichever is shorter, following the first year of service if previous calibrations were within normal adjustment ranges identified by the manufacturer.

### 2.8 Human Element

2.8.1 Establish and document operating procedures, and train all operating and maintenance personnel in its implementation. See Data Sheet 10-8, *Operators*, for more information.

2.8.2 Establish and document an emergency response plan for all facilities and train all operating and maintenance personnel in its implementation. This includes steps to maximize refrigerated space temperature holding time. See Data Sheet 10-1, *Pre-Incident Planning*, for more information.

Ammonia refrigeration systems have certain inherent characteristics requiring special consideration. A guide for developing an emergency plan for ammonia systems is provided in Appendix C.

2.8.3 Provide adequate and proper equipment, including vapor detectors, protective clothing, fans, chemicals, self-contained breathing apparatus (SCBA), to execute the emergency response plan.

2.8.4 Instruct all operating personnel in the care, use, and limitations of personal protective equipment.

2.8.5 Conduct periodic emergency response drills.

### 2.9 Contingency Planning

2.9.1 Provide a formal, written contingency plan and practice it to ensure the ready availability of contamination remediation services, isolation of the affected area, additional ventilation, rental equipment for smaller systems, and relocation services for stock (such as temporary refrigerated trailers) in the event of an emergency.

### 2.10 Ignition Source Control

2.10.1 Locate electrical equipment not associated with the refrigeration process outside the machinery room. It is particularly important to have separate electrical rooms cut off by suitable walls when using flammability classification 2L, 2, and 3 refrigerants.

2.10.2 In machinery rooms using flammability classification 2 and 3 refrigerants, provide Class I, Div (Zone) 2 rated electrical equipment in accordance with Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations*.

2.10.3 For machinery rooms in which a flammability classification 2L refrigerant is used, provide ignition source control as follows:

A. Install an FM Approved refrigerant detection system arranged to activate at levels of no more than 1000 ppm, alarm to a continuously attended location, activate emergency ventilation (see 2.5.5 and 2.5.6), and shut down all electrical equipment and energized valves (except ventilation systems).

B. Where the machinery room is not electrically isolated as described above, install Class 1, Div (Zone) 2 equipment.

2.10.3.1 Locate detectors in accordance with manufacturers' requirements. Suggested locations are in the vicinity of potential releases (e.g., near compressors and large receivers).

## 3.0 SUPPORT FOR RECOMMENDATIONS

### 3.1 Refrigerant Classification

Refrigerants are classified into groups based on safety-related characteristics as shown in Figure 4. The classification is made up of letters (A or B) and numbers (1, 2, or 3). This classification system has been harmonized across North America and Europe in ASHRAE, IIR, and ISO standards.

The first character represents the toxicity classification. Toxicity in this context is defined as the ability of a refrigerant to be harmful or lethal due to acute or chronic exposure by contact, inhalation, or ingestion. Toxicity is an important characteristic for employee safety, but also for the potential contamination of a commodity in storage. Class A refrigerants have an operational exposure limit (OEL) of 400 ppm or greater. Class B refrigerants have an OEL of less than 400 ppm.

The second character represents the flammability classification of the refrigerant. Flammability class 1 refrigerants display no flame propagation when tested in accordance with the refrigerant classification standard. Flammability class 2 and 3 refrigerants will both display flame propagation when tested at 140˚F (60˚C). Class 2 refrigerants have a lower flammability limit (LFL) of greater than 0.0062 lb/ft$^3$ (0.10 kg/m$^3$). Class 3 refrigerants have a LFL of less than 0.0062 lb/ft$^3$ (0.10 kg/m$^3$). For refrigerants that have slow flame propagation speed (≤ 3.9 in./s (10 cm/s)), an additional character, "L" is added to the classification to indicate "low flammability."

The refrigerant classification is usually included in Section 16, Other Information, of the globally-harmonized Safety Data Sheet (SDS). Safety classifications of common refrigerants are included in Table 3. If it is not included on the SDS, check the manufacturer's website for more information.

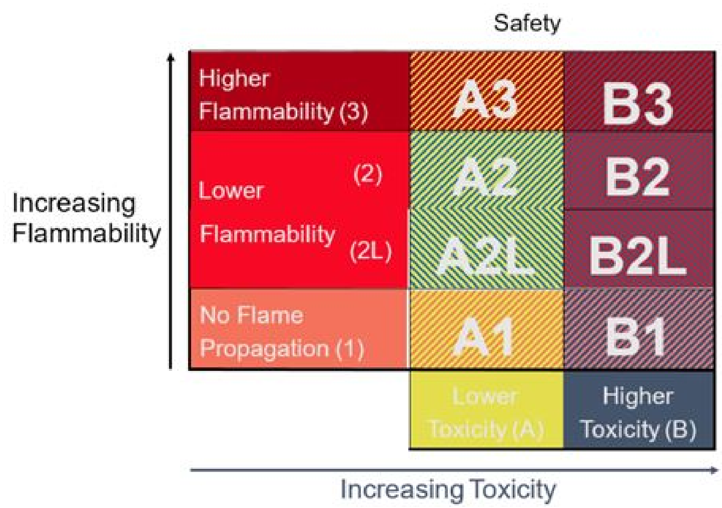


*Fig. 4. Refrigerant classification*

*Table 2. Safety Classifications of Common Refrigerants*

| *Classification* | *Denomination* | *Composition or Chemical Formula* | *Safety Classification* |
|---|---|---|---|
| Inorganic Compound | | | |
| R717 | Ammonia | $NH_3$ | B2L |
| R718 | Water | $H_2O$ | A1 |
| R744 | Carbon Dioxide | $CO_2$ | A1 |
| Organic Compound | | | |
| Hydrocarbons | | | |
| R170 | Ethane | $CH_3CH_3$ | A3 |
| R290 | Propane | $CH_3CH_2CH_3$ | A3 |
| R600a | Isobutane | $CH(CH_3)_2CH_3$ | A3 |
| R1234yf | 2,3,3,3-tetrafluoro-1-propene | $CF_3CF{=}CH_2$ | A2L |
| Halocarbons | | | |
| R11 | trichlorofluoromethane | $CCl_3F$ | A1 |
| R12 | dichlorodifluoromethane | $CCl_2F_2$ | A1 |
| R22 | chlorodifluoromethane | $CHClF_2$ | A1 |
| R32 | difluoromethane (methylene fluoride) | $CH_2F_2$ | A2L |
| R125 | pentafluoroethane | $CHF_2CF_3$ | A1 |
| R134a | 1,1,1,2-tetrafluoroethane | $CH_2FCF_3$ | A1 |
| R143a | 1,1,1-trifluoroethane | $CH_3CF_3$ | A2L |
| R152a | 1,1-difluoroethane | $CH_3CHF_2$ | A2 |
| Azeotropic Mixtures | | | |
| R502 | R-22/115 (48.8/51.2) | | A1 |
| R507a | R-125/143a (50.0/50.0) | | A1 |
| Zeotropic Mixtures | | | |
| R404a | R-125/143a/134a (44.0/ 52.0/4.0) | | A1 |
| R407c | R-32/125/134a (23.0/25.0/ 52.0) | | A1 |
| R410a | R-32/125 (50.0/50.0) | | A1 |

### 3.2 Refrigerant Replacement

Since the phase-out of R-11 in the 1980s, the refrigeration industry has continued to research refrigerant blends that provide the highest possible thermal efficiency while balancing the environmental impacts, such as ozone depletion potential (ODP) and global warming potential (GWP). Some of these new refrigerants are methane and propane blends, and present a flammability hazard. It is important to understand the implications of a change of refrigerant, even where a refrigerant is being offered as a “drop-in” replacement.

### 3.3 Multiple Machinery Rooms

The current trend in the refrigeration industry is to install multiple, smaller machinery rooms in a refrigerated plant or warehouse. This can provide several benefits, including reducing the total on-site refrigerant charge, limiting the impact of an equipment outage, and reducing energy costs. The recommendations of this property loss prevention data sheet should be applied to any machinery room at a facility.

### 3.4 Loss History

Table 3 describes the mechanical refrigeration losses experienced by FM clients in the period from January 2006 through June 2017. While representing a relatively small number of incidents, contamination is the loss leader in terms of loss cost. All contamination incidents involved ammonia refrigeration systems where the leak either occurred in the refrigerated area or there was inadequate separation between the machinery room and refrigerated area, allowing ammonia gas to migrate to the refrigerated area. The causes of the ammonia releases included the following:

- Mechanical failure of a fan coil unit causing the fan blade to impact and rupture an ammonia line
- Ammonia line impacted by forklift
- Flange failure on an ammonia line
- Mechanical room fire resulted in ammonia release and migration into refrigerated area
- Compressor failure
- Operator error

The leading cause of losses by frequency is mechanical breakdown of equipment. The most common equipment cited in mechanical breakdown was the compressor. Compressors, including maintenance and inspection, are covered by Data Sheet 7-95, *Compressors*.

The second leading cause of losses is electrical breakdown of equipment. Electrical breakdown was often related to electrical short circuits, arcing, or failure in controls such as control panels, temperature sensing devices, and compressor motors. These issues are addressed in other FM Property Loss Prevention Data Sheets. Several other electrical breakdown losses were associated with power outages.

*Table 3. FM Mechanical Refrigeration Losses by Peril, 2006-2016*

| *Peril* | *Percentage of Losses* | *Percentage of Loss Cost* |
|---|---|---|
| Contamination | 6.9% | 62.8% |
| Temperature Change | 9.0% | 11.6% |
| Electrical Breakdown | 27.1% | 9.6% |
| Mechanical Breakdown | 45.7% | 8.4% |
| Fire | 2.1% | 3.7% |
| Miscellaneous | 3.7% | 1.5% |
| Escaped Liquids Damage | 1.1% | 1.4% |
| Pressure Equipment Breakdown | 3.7% | 0.8% |
| Wind and Hail | 0.5% | 0.2% |
| Grand Total | 100.0% | 100.0% |

## 3.5 Illustrative Losses

### 3.5.1 Ammonia Contamination in Refrigerated Warehouse.

An ammonia leak occurred at a 225,000 ft$^2$ (21,000 m$^2$) refrigerated storage facility consisting of nine separate refrigerated areas. A maintenance employee mistakenly removed a refrigerant drain valve on an evaporator unit, causing the release of ammonia. Ammonia detectors were only installed in the machinery room and two of the nine refrigerated areas. The plant was not equipped with an emergency shutdown system for the refrigeration equipment. The refrigeration system was manually shut down and the plant evacuated. Ammonia vapors migrated from the area where the leak occurred to three additional refrigerated areas through open doorways in interior walls. Ammonia contamination mitigation efforts proceeded for approximately four days. In addition to the loss of product in storage, the brass sprinklers in the affected areas were replaced due to the chemical reaction between ammonia and brass.

### 3.5.2 Ammonia Explosion in Machinery Room at a Frozen Food Production Facility.

An ammonia release and subsequent explosion occurred at a 170,000 ft$^2$ (16,000 m$^2$) frozen food production facility. The machinery room was located within the envelope of the building being served with two exterior walls. The two interior walls separating the machinery room from the main plant area were 8 in. (200 mm) concrete block. The machinery room was equipped with ammonia detectors, but the detectors were not arranged to alarm to a constantly-attended location. At the time of the release, the ammonia refrigeration system was shut down in preparation for the installation of a new blast freezer. At approximately 2:00 am, a security guard noticed a high-pitch noise coming from the machinery room, likely the ammonia detector alarm. The guard determined that there was an ammonia leak in the machinery room and contacted appropriate personnel and first responders. An explosion occurred in the machinery room at approximately 2:45 a.m. with no fire following. The explosion resulted in damage to the roof requiring complete replacement, complete destruction of the two interior concrete block walls, partial destruction of a second interior wall located across an interior corridor from the machinery room walls, and damage to the exterior metal panel walls. Vessels and compressors were lightly damaged and were returned to service after repair. The cause of the release was found to be an inadequately-supported pipe elbow between a receiver and liquid return unit that failed at a threaded connection due to torsional stress. Production at the facility ceased for approximately two weeks for mitigation and repair.

## 4.0 REFERENCES

### 4.1 FM

Data Sheet 1-2, *Earthquakes*
Data Sheet 1-44, *Damage Limiting Construction*
Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*
Data Sheet 3-26, *Fire Protection Water Demand for Nonstorage Sprinklered Properties*
Data Sheet 5-1, *Electrical Equipment in Hazardous Locations*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-43/17-2, *Process Safety*
Data Sheet 7-49, *Emergency Venting of Vessels*
Data Sheet 7-95, *Compressors*
Data Sheet 10-1, *Pre-Incident Planning*
Data Sheet 10-8, *Operators*textFM Approval Standard 6340, *Toxic Gas and Oxygen Depletion Detectors*

### 4.2 Others

ANSI/ASME B31.5-2016, *Refrigeration Piping and Heat Transfer Components*.

ANSI/ASHRAE 15-2016, *Safety Standard for Refrigeration Systems*.

ANSI/ASHRAE 34-2016, *Designation and Safety Classification of Refrigerants*.

EN 378-2016, *Refrigerating Systems and Heat Pumps - Safety and Environmental Requirements.*

IIAR 2-2014, *Standard for Safe Design of Closed-Circuit Ammonia Refrigeration Systems*.

NFPA 70-2017, *National Electrical Code*.

Smith, M.A., *Ammonia Spills and the Effect of Ammonia on Products Stored in Refrigerated Warehouses*, The Refrigeration Research Foundation, 1987.

## APPENDIX A GLOSSARY OF TERMS

*Emergency ventilation*: The movement of air to reduce the risk or severity of fire or explosion following process upset.

*FM Approved*: Products and services that have satisfied the criteria for FM Approval. Refer to the *Approval Guide*, an online resource of FM Approvals, for a complete listing of products and services that are FM Approved.

*Ignitable liquid*: Any liquid or liquid mixture that is capable of fueling a fire, including flammable liquids, combustible liquids, inflammable liquids, or any other term for a liquid that will burn. An ignitable liquid is one that has a fire point.

*Ventilation*: The movement of air for general purposes, such as climate control and removing heat generated by refrigeration equipment.

## APPENDIX B DOCUMENT REVISION HISTORY

January 2018. This document has been completely revised. Major changes include the following:

A. Recommendations for flammable refrigerants have been moved to a new section for better visibility.

B. Indirect systems are recommended for new construction when flammable refrigerant or ammonia is used.

C. Automatic emergency shutdown is recommended for locations where a flammable refrigerant or ammonia is used.

D. Refrigerant classifications have been updated to be consistent with international standards for refrigerant identification.

E. Recommendations related to critical piping and controls have been have been incorporated into DS 7-13 from DS 12-61.

F. Added recommendation for emergency ventilation controls located outside areas where refrigerant leaks may occur.

G. Added recommendation for areas where lower emergency ventilation rates are required to comply with local regulations.

H. Added recommendation for isolation valves at critical points in the system to minimize the amount of refrigerant released and facilitate drainage.

I. Updated recommendations on calibration frequency of ammonia or refrigerant detectors.

J. Updated human element recommendations to be consistent with DS 10-8 and DS 10-2.

K. Added recommendation for a formal, written contingency plan to address contamination remediation, isolation, rental equipment, and relocation of stock.

L. Updated loss history and illustrative losses.

October 2014. Interim revision. Minor editorial changes were made.

January 2012. Terminology related to ignitable liquids has been revised to provide increased clarity and consistency with regard to FM Global's loss prevention recommendations for ignitable liquid hazards.

May 2007. Editorial changes were made for this revision.

September 2005. The ventilation criteria in 2.8.3 was modified for considerations of practicality.

May 2003. Minor editorial changes were made for this revision.

September 2002. Clarification was made to the recommendation 2.5.1.

January 2000. This revision of the document has been reorganized to provide a consistent format.

October 1975. Document was updated from information provided in the Handbook of Industrial Loss Prevention.

## APPENDIX C SUPPLEMENTAL INFORMATION

### C.1 General

Mechanical refrigeration systems use a vapor compression cycle employing a refrigerant that changes state from liquid to vapor as it absorbs heat in the evaporator.

All vapor refrigeration systems, regardless of the type of compressor used, operate because of a difference in pressure that permits the collection of heat by the refrigerant at a low temperature and disposal at a higher temperature. To establish the proper heat flow direction in the evaporator, the suction vapor pressure must have a value sufficiently low so that the corresponding saturation temperature will be below the source temperature. The discharge pressure must be sufficiently high so that the corresponding condenser temperature will exceed the temperature of the heat sink to ensure the necessary rate of heat transfer. The compressor provides the means of establishing the necessary difference between the “low side” and “high side” pressures. A simplified sketch of a basic refrigeration system is shown in Figure 3. Refrigerating systems are divided into two classes in accordance with the method of extracting heat as follows:

A direct system, such as the example in Figures 5 and 6, is one in which the evaporator or condenser of the refrigerating system is in direct contact with the air or other substances to be cooled or heated. Figure 6 provides a real-world example of a direct refrigeration system with multiple compressors that has been painted to provide clear indications of the purpose and contents of equipment.

An indirect system, such as the example in Figure 7, is one in which a secondary coolant, cooled or heated by the refrigerating system, is circulated to the air or other substance to be cooled or heated. The secondary coolant may be sprayed into a cooling chamber or circulated through pipes in either a vented or a closed system.

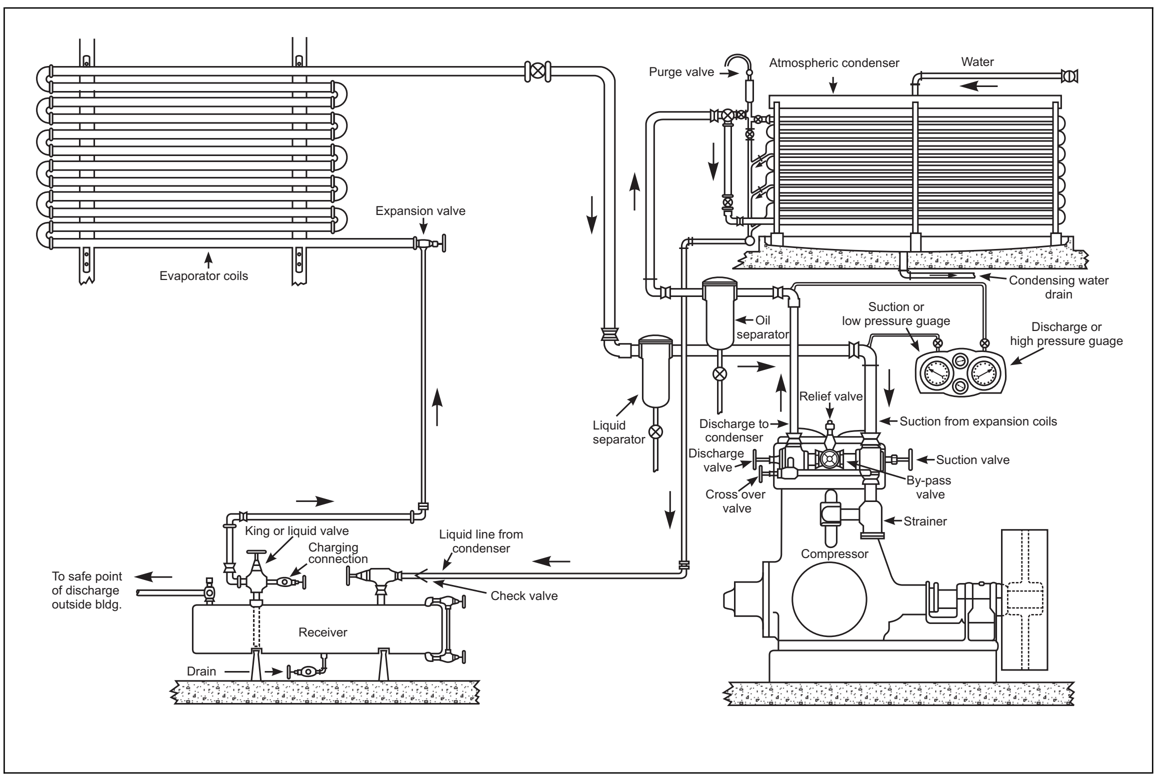


*Fig. 5. Typical direct refrigeration plant*

*Fig. 6. Direct refrigeration system machinery room*

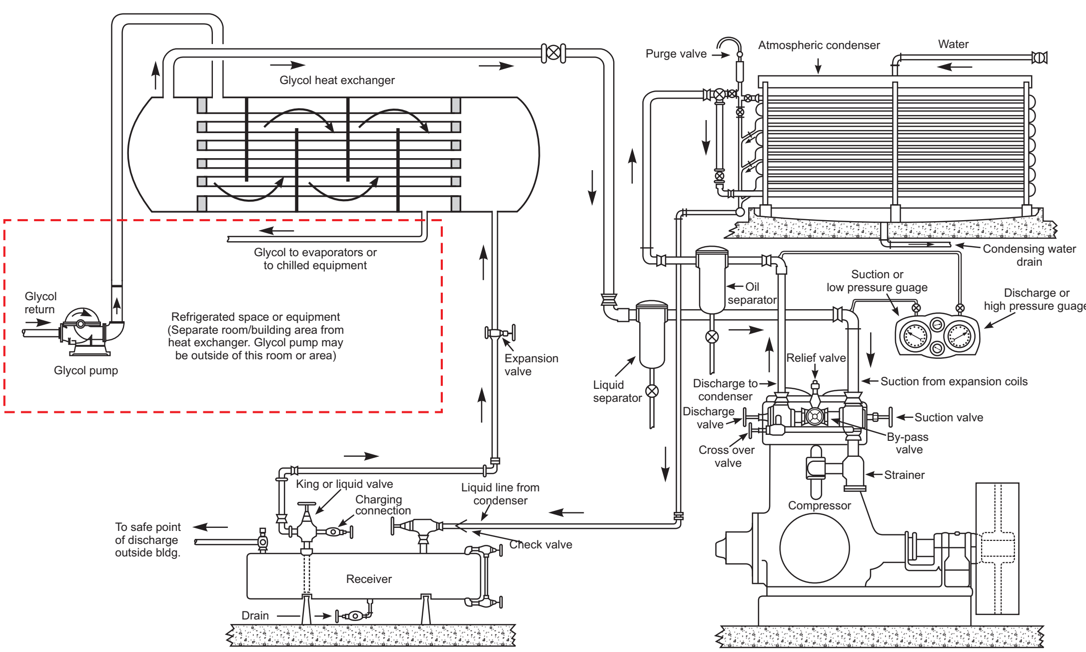


*Fig. 7. Typical indirect refrigeration plant*

### C.1.2 Ammonia Effects on Personnel

Table 4 is a brief summary of the effects of ammonia. As a result, specific training is needed to ensure proper emergency response, which will also reduce subsequent product damage.

*Table 4. Effects of Ammonia*

| *Ammonia Concentration*[1] | *Effect on Personnel* |
|---|---|
| 3,000 ppm (0.3 percent) | Highly toxic. Area accessible for short periods with a portable oxygen supply, and a full-face oxygen mask. High degree of skin irritation. |
| 1,000 ppm (0.1 percent) | Toxic. Accessible with cartridge type gas mask but only for short periods. |
| 500 ppm | Very annoying to throat, lungs, nose and eyes. Essentially accessible only with gas mask. Still very annoying to skin. |
| 200 ppm | Still very annoying to all but experienced ammonia personnel. Gas mask recommended. |
| 100 ppm | Very noticeable, and fairly annoying. Experienced personnel can tolerate this indefinitely. |
| 20 ppm | Distinct, but not very annoying. |
| 10 ppm | Noticeable, but only mildly. |
| 5 ppm | Scarcely detectable, and not at all annoying. |

Source: IAR Operations Manual—1987

### C.1.3 Ammonia Explosibility

Table 5 lists a comparison of ammonia explosibility at near stoichiometric concentration compared to pentane at its near stoichiometric concentration in a similar test bomb.

*Table 5. Comparison of ammonia Explosibility to Pentane*

| | *Maximum Explosion Pressure psi (bar)* | *Rate of Pressure Rise psi/sec (Bar/sec)* | |
|---|---|---|---|
| | | Average | Maximum |
| Ammonia | 86 (5.9) | 141 (9.7) | 260 (17.9) |
| Pentane | 118 (8.1) | 2750 (189.5) | 6502 (448) |

As can be seen from this data, ammonia burns more slowly (rate of pressure rise) than a typical hydrocarbon and produces a somewhat lower maximum pressure. This, to a degree, explains why ammonia explosions generally seem to be less violent and less damaging.

The same data source compares these two materials for ease of ignition and on a similar basis shows ammonia to be much more difficult, but it still ignites. (Reported minimum ignition energy of 1-2 mj for pentane-air, but greater than 40 mj for ammonia-air.)

## C.2 Ammonia Systems

### C.2.1 Process Information

Anhydrous ammonia is classified as a B2L refrigerant, indicating that is high toxicity (B) and low flammability (2L).

The ammonia system of refrigeration consists of a compressor designed to compress the low pressure ammonia gas leaving the evaporator to a pressure of approximately 150 psi (1 MPa) (10 bars). The gas is then discharged into the condenser.

When ammonia gas is under a pressure of 150 psi (1 MPa) (10 bars), it will liquefy at a temperature of 78°F (25°C). Therefore, if water, at a temperature of 70°F (21°C) or less, is circulated through pipes in the condenser, the gas will liquefy and give off its latent heat to the water.

The liquid ammonia in the condenser is then stored in a receiver or accumulator and from there is allowed to flow out through a small pipe to the expansion coils (evaporator). On this pipe is a valve which controls the amount of liquid passing. As soon as the liquid passes through this valve the pressure is greatly reduced so the liquid vaporizes and reverts again to a gas, and in doing so, absorbs heat from the surrounding atmosphere of the room, which becomes colder. If the coils are placed in a glycol (cooled fluid, whether it be water, glycol, or other fluid) tank, the glycol is chilled. When the ammonia has absorbed sufficient heat to be converted to a low-pressure gas and liquid, it flows back to the compressor and the operation is repeated.

Ammonia refrigeration systems are particularly common in the food industries due to the efficiency and economy of large-scale systems. With increasing restrictions on halocarbon use, due to atmospheric ozone depletion effects, ammonia will be appearing in more places.

### C.4 Cleanup after an Ammonia Release

As evidenced by the loss statistics, product contamination from an ammonia release is much more likely than a fire or explosion. Preventive maintenance and good work practices are the best way to prevent an ammonia release but once released, the damage to property can be minimized by prompt and effective action. This includes isolating and plugging the source of the leak, controlling ventilation to limit spread of ammonia vapors, sealing off areas not already exposed, and relocating goods to isolated clean areas, such as refrigerated trailers. Steps can then be taken to decontaminate exposed areas and goods.

#### C.4.1 Ventilation

The first line of defense after a spill of ammonia is ventilation. The more quickly the ammonia vapors can be dispersed the less the product damage and the easier to complete decontamination. Where emergency ventilation is not installed, the emergency response plan should include provisions for ventilation, including sources of equipment. The typical arrangement is to set up the fans to exhaust the area, with fresh air inlet opposite the exhaust.

This method would not be very effective if the room that is pressurized can’t be reasonably sealed from other areas. Use of positive pressure ventilation is most effective when the exhaust opening can be provided close to the source of the spill or leak. It has the added advantage of providing a direct fresh air pathway that salvage teams can use for entry.

#### C.4.2 Absorption

Ammonia is readily soluble in water, forming ammonium hydroxide, so using a water spray or fog can be an effective way of absorbing the vapors. With perfect mixing about 1.1 lb (.50 kg) water is needed to absorb 1 lb (.45 kg) of ammonia. In a typical spill situation, three or more times as much water than ammonia is likely to be needed. There also must be a way to dispose of the water/ammonia solution. Ice formation is possible and warming the area may be necessary. Water damage to the product is also possible, requiring it to be relocated or otherwise protected.

#### C.4.3 Neutralization

##### C.4.3.1 Carbon Dioxide

Ammonia reacts readily with carbon dioxide ($CO_2$) in the presence of water vapor to form ammonium carbonate, a harmless white powder. This powder, however, decomposes back to ammonia vapor at 136°F (58°C) so care must be taken to remove and dispose of the powder. Again, with perfect mixing, about 1.3 lb (.60 kg) of carbon dioxide plus 1.1 lb (.50 kg) of water would be needed to dispose of each pound (.45 kg) of ammonia.

Carbon dioxide is available as a stored liquid in cylinders (and fire extinguishers) or as dry ice.

When using $CO_2$ as a neutralizing agent, care must be taken to minimize the personnel hazard caused by oxygen displacement. In general it is recommended that no more than 1 lb per 100 $ft^3$ (2.2 kg per 2.8 $m^3$) of room volume be used for any one treatment. A treatment would last about 12 hours and good circulation needs to be maintained in the treated space for $CO_2$ to do the job. Also, warming of the space will increase the rate of ammonia dissipation when it has been absorbed by packaging materials.

##### C.4.3.2 Other Acid Gases and Liquids

Sulfur dioxide, acetic acid (vinegar), and citric acid may be used to disperse the last traces of ammonia odors. Sulfur dioxide ($SO_2$) forms relatively corrosive sulfuric acid vapors and is carefully monitored in connection with air pollution. The U.S. Food and Drug Administration (FDA) has also established regulations on the use of $SO_2$ or other sulfiting agents on food to be sold or consumed in the fresh or raw state.

Acetic acid is relatively non-reactive with ammonia but is slightly more effective than water in reducing ammonia odors. It can be sprayed full strength throughout the affected area to reduce traces in cracks and crevices.

Citric acid has about the same effects as acetic acid and would be used similarly.

### C.5 Effects of Ammonia on Foods

C.5.1 Product Contamination

The degree of damage resulting from an exposure to ammonia is determined by the concentration of ammonia, duration of exposure, temperature, product, and packaging. Long-term exposure to ammonia at low concentrations may be as damaging as short-term exposure at higher concentrations.

Ammonia damage tends to increase with increasing temperatures and moisture content, as well as with other factors.

Acid products such as fruits and vegetables and products high in fat, such as nuts, ice cream, milk, and milk products, are especially susceptible to ammonia injury. The quantity of air in a product allows ammonia to penetrate, thus ice cream and marshmallows generally cannot be salvaged. Shrimp and other seafood are especially prone to absorbing ammonia. Frozen products are slightly less susceptible to contamination due to lower metabolism rates.

Seeds and seedlings are also affected by ammonia. High concentrations of ammonia reduce germination and seedling growth. However, long-term, low-level exposure could be toxic. Seed with higher moisture content would be more susceptible.

Product quality also plays a significant role in susceptibility. Newly harvested produce and nuts are more resistant to ammonia injury than produce stored for several months. Nuts in shell show lesser susceptibility to ammonia damage than shelled nuts.

Packaging plays a significant role in susceptibility to ammonia injury. Any material capable of protection against changes in moisture content due to fluctuating humidity would also tend to protect against ammonia fumes. Well-sealed polyethylene and PVC packaging offer good protection against ammonia fumes when frozen foods are exposed for up to 24 hours. Unpackaged foods rapidly become unacceptable in terms of flavor, usually within 15 minutes to one hour of exposure.

Ammonia may become trapped by packaging material, especially corrugated cardboard. This material stubbornly resists attempts to eliminate odor. Product may be exposed to residual ammonia in the packaging material. Re-cartoning can be time-consuming but is effective in limiting product exposure.

Another result of ammonia exposure is thawing as a result of lowered melting points.

A method of salvaging frozen foods involves removing product from the corrugated master carton, running the product through a blast freezer to evaporate the ammonia, and repackaging.