PREVENTION OF FREEZE-UPS

Table of Contents

Page

List of Figures

1.0 SCOPE

This data sheet provides guidance to prevent or reduce weather-related freezing of equipment and property. It applies to locations where the 100-year return period daily minimum temperature is 20°F (-6.7°C) or colder as shown in the FM Worldwide Freeze Map.

Most locations in freeze-prone areas are susceptible to severe freeze damage when site electricity and/or natural gas is lost, impairing heating systems. History has demonstrated these utilities can be out of service for several days with freezing conditions. Outdoor process equipment, conveyors, instrument lines and buildings in areas where freeze is not common are especially vulnerable to freeze damage under these conditions. This data sheet provides guidance to assist in planning for loss of utilities during freezing weather events.

For freeze protection of fire protection suction and gravity tanks see FM Property Loss Prevention Data Sheets 3-2, *Water tanks for Fire Protection*; 3-4, *Embankment-supported Fabric Tanks*; and 3-6, *Lined Earth Reservoirs or Fire Protection.*

Freeze pre-incident and emergency response planning can be found in FM Property Loss Prevention Data Sheet 10-1, *Pre-Incident and Emergency Response Planning.*

1.1 Hazards

Substantial damage can occur when temperatures drop below the freezing point of water and other fluids. Expansion and contraction can break piping and other containment systems, presenting an escape of the liquids when the temperature subsequently rises above their freezing point after the freezing event.

Some of the most severe damage can be seen at facilities in the moderate, temperate zone (middle latitudes), including subtropical regions, in which freeze is expected to be infrequent, short-term, and moderate. In these regions, inadequate insulation and insufficient heat can result in broken water piping, impaired fire protection systems, and resultant water damage. Impaired fire protection will leave the facility vulnerable to an uncontrolled fire.

In areas where freeze is common, freeze losses often result from a change within a facility, such as not replacing insulation after a repair or leaving a door or window open.

Freeze can also interrupt production processes. Freezing of condensation in instrument air tubing can prevent instrument signals from being transmitted, forcing a process to be stopped. In extreme cases, instrument tubing may rupture or instruments may be damaged, resulting in a longer interruption of business to repair or replace the damaged equipment.

See the following FM documents for additional information:

- FM Property Loss Prevention Data Sheet 10-1, *Pre-Incident Planning and Emergency Response*
- *Freeze Emergency Response Plan (F7650)*
- Freeze-up Checklist (P9521)
- UTH: *Freeze (P0148)*
- UTH: *Idle, Vacant or Strikebound Facilities (P0274)*
- *Protecting Your Facilities from Winter Storms (P0101)*

1.2 Changes

July 2022. Full revision. The following significant changes were made:

A. Clarified existing and added new recommendations for locations where the 100-year return period daily minimum temperature (100-year DMT) is 20°F (-6.7°C) or colder as shown in the new FM Global Worldwide Freeze Map, available online at www.fmglobal.com.

B. Replaced freeze maps and tables in Appendix D with an overview map of freeze areas.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

Recommendations are applicable to locations where the 100-year return period daily minimum temperature (100-year DMT) is 20°F (-6.7°C) or colder as shown in the FM Worldwide Freeze Map, available online at www.fmglobal.com.

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

2.2 Construction and Location

2.2.1 Provide adequate fixed heat to maintain a temperature higher than 40°F (4°C) inside buildings containing water-filled piping or other liquids with a freezing point less than 40°F (4°C). This includes areas where above-ground liquid piping passes through stairwells or passageways, rooms with exterior wall(s), above suspended ceilings near exterior walls, and other concealed spaces with fluid systems.

2.2.2 For heated buildings, provide building insulation according to applicable ASHRAE standard in the United States, or equivalent outside the US.

- ASHRAE 90.1-2019 (I-P), Energy Standard for Buildings Except Low-Rise Residential Buildings, or
- ASHRAE 90.2-2018, Energy Efficient Design of Low-Rise Residential Buildings

2.2.3 When possible, avoid installing water or other fluid lines (including for fire protection systems) in exterior walls and in walls adjacent to unheated building areas.

2.2.4 Provide heat to maintain fire pump rooms with electric motors above 40°F (4°C) and those with diesel engine drives above 70°F (21°C). See details in Data Sheet 3-7, *Fire Protection Pumps.*

2.2.5 Locate fire pump suction intake and pipe from an open reservoir below the frost level underground and deep enough in water to prevent ice obstructions.

2.2.6 Provide an insulated heated enclosure with temperature monitoring to a constantly attended location for any sprinkler system riser that is located exterior to a heated building including preaction valves, deluge valves and dry pipe valves.

2.2.7 Use FM Approved dry pipe, pre-action, dry pendant, or antifreeze systems where any portion of a system cannot be reliably maintained at a minimum of 40°F (4°C). Only use systems when appropriate for the hazard per FM Property Loss Prevention Data Sheets.

2.2.8 Provide freeze protection for private fire service mains in accordance with Data Sheet 3-10, *Installation/ Maintenance of Private Fire Service Mains and Their Appurtenances*.

2.2.9 Insulate wet-pipe sprinklers in ceilings with unheated attics above, following NFPA 13R, *Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies.*

2.2.10 Provide open air circulation (no barriers to restrict air movement) or direct heat to wet-pipe sprinklers adjacent to exterior walls that are above suspended ceilings. See Section 3.4, *Freeze Protection for Wet-Pipe Sprinklers Above Suspended Ceilings with Restricted Airflow.*

2.3 Protection

2.3.1 Provide low temperature alarms and FM Approved water leak detection devices with monitoring that alarm at a constantly attended location in accordance with Data Sheet 1-24, *Protection Against Liquid Damage.*

2.4 Equipment and Process

2.4.1 Complete a process freeze hazard analysis considering loss of utilities; determine targeted freeze protection and prevention actions for equipment, stock and work-in-process. The analysis should focus on areas and equipment in need of adequate freeze protection for three modes of site operation: continued operations, idling of the site during freezing weather, and/or complete shutdown before or during a freeze event. The analysis should be documented, should include resources needed, and should prioritize prevention and mitigation measures for all three modes of site operation.

Hazard analysis can utilize procedures outlined in FM's Data Sheets 7-43, *Process Safety*, and Data Sheet 10-1, *Pre-Incident and Emergency Planning*. This hazard analysis is commensurate with the site operations and should include the following where applicable:

A. Develop a definitive plan and timeline for when a site shutdown and/or site curtailment/idling is needed.

B. Loss of incoming utilities including electricity, natural gas and those on-site operated by a third party, for at least three days. In most situations this will result in loss of building heat and other freeze protection.

C. Consider lack of site access due to snow or freezing precipitation. Site accessibility varies based on the capabilities of the local authorities to remove snow and treat icy roads, especially when freezing rain occurs. Areas not subject to regular winter weather typically lack equipment and resources and roads in a large region may be impassable for up to five days. It may not be possible to deliver gasoline and diesel fuel to the site.

D. Heat from boilers and/or reduced operations may be considered during this isolation period if there are adequate resources on site. This includes power and fuel supplies to maintain reduced operations that prevent freeze damage, on-site emergency response team, and on-site operating personnel prior to and throughout the freeze event.

E. Consider the impact of utility loss on refrigeration or climate control for valuable perishable items.

F. Develop a priority load-shedding schedule for electrical, natural gas, steam and/or other critical utilities to reduce damage when supplies are curtailed or lost. Identify the processes that can be taken off-line quickly with little damage to equipment from freeze or damage to work-in-process.

G. Consider the need for re-starting from a complete shut-down condition to an operating condition without the assistance from an outside power system.

H. Continue operating outside, uncovered conveyors needed for critical on-site utilities during a freeze event.

2.4.2 Provide freeze protection to the 100-yr DMT for critical equipment identified in the process freeze hazard review. Include the following:

- Equipment and process lines that run outdoors or through unheated/unattended buildings
- Service or process-water lines, non-self-draining steam traps or liquid drains, dead-legs and high pour-point fuel oil lines
- Boilers including draining of idle equipment, drain valves on condensate return lines, removal of low points and dead ends where possible, steam traps with drain valves, low water cutoff devices with minimal exposed piping, etc.
- Transmitters
- Sensing lines including all differential pressure measurement device sensing lines
- Instrumentation including those supplied with nitrogen
- Non freeze valves in fluid service
- Inlet air systems
- Components dependent on lubrication for proper operation
- Fuel, air, and hydraulic filters
- Piping and wiring
- Superheaters and reheaters
- Inlet air chiller coils
- Demineralized water tanks
- Water cooled equipment
- Equipment based on previous freezing experience

Update this list regularly to include new equipment and to remove retired equipment.

2.4.3 Drain or circulate water systems and other susceptible systems, except fire protection systems, to prevent freezing when a temperature of 40°F (4°C) cannot be maintained. See Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*, for procedures to protect fire protection systems from freeze damage.

2.4.3.1 For HVAC or other systems where water is circulated and power is available, determine whether they can be best protected from the 100-year DMT by maintaining water circulation or by draining.

2.4.3.2 For service water or other systems where water is not circulated but water is available, determine whether the best freeze protection for the 100-year DMT is by draining, periodically opening faucets or water outlets or leaving them open with a trickle flow.

2.4.3.3 Drain or remove other liquids that cause damage as they solidify with the expected 100-year DMT. Follow manufacturer's instructions.

2.4.4 Use temporary electric or fuel-fired heaters to prevent freeze damage to small building areas or equipment under the following conditions:

A. Use electric heaters listed for hazardous locations if equipment is in a hazardous location.

B. Locate the heater away from combustible materials in accordance with the manufacturer's instructions.

C. Locate the heater so it will not be tipped over or damaged by moving objects. Provide guard posts if necessary.

D. Provide the heater with a tip-over sensor that shuts off the unit and prevents fuel from spilling (if applicable).

E. Do not move or refuel the heater while it is operating or still hot.

F. Locate fire extinguishers nearby portable heaters. Provide a small water hose if it is not subject to freezing temperatures.

G. Maintain adequate ventilation according to the manufacturer's directions.

H. Maintain and operate the heater according to the manufacturer's instructions.

I. Have trained staff monitor portable heaters for proper operation and fire-safe conditions.

J. When fueled heaters such as salamanders are used (which require electricity to operate), they should be indirectly fired and used outdoors away from combustible buildings or materials. Under emergency circumstances to prevent imminent freeze damage, they may be used in large, open noncombustible buildings with non-combustible occupancies (e.g., steel mills, metal working, etc.).

2.4.5 Provide emergency power generation to protect key equipment based on the process freeze hazard evaluation in accordance with FM's Data Sheet 5-23, *Design and Protection for Emergency and Standby Power Systems*. Provide on-site fuel to supply this generation for at least three days.

2.4.6 Provide freeze protection to prevent the freezing of susceptible process instrumentation and control lines for key exposures identified in process freeze hazard review by one of, or combination of, the following methods:

- FM Approved heat tracing
- Steam tracing
- Steam jacketing
- Non-freeze solutions
- Frostproof casings
- Insulated coverings
- Revision or elimination of vulnerable piping or equipment from freeze prone areas.
- Air drying according to ANSI/ISA 70.0.0,1 *Quality Standard for Instrument Air or equivalent outside the US.*

This includes air with a pressure dew point at the dryer outlet that is 18°F (10°C) below the temperature on the FM Worldwide Freeze Map. [If the temperature on the FM Worldwide Freeze Map is 10°F (-12.2C), then dryers should provide air with a dew point of -8°F (-22C)]. Desiccant type air dryers may be needed to achieve the recommended dew points.

For descriptions of these items, as well as some advantages and disadvantages of various heat tracing systems, see Appendix C.

2.4.7 Eliminate any dead-legs in the process piping where freeze breakage can cause a release of hazardous material or disrupt operation of key infrastructure identified in the process freeze hazard reviews.

2.4.8 Use screens with minimum ¾ in. (19 mm) openings on vents for storage or process tanks and vessels.

2.4.9 Provide wind screens or freeze protection panels for exposed piping or equipment.

2.4.10 Provide the following for air handling units: (See DS 1-45, *Air Conditioning and Ventilation Systems*, and Section 3.5 of this document for additional information.)

2.4.10.1 Provide a freeze stat over the entire surface of water coils in air handling units. Install freeze stat capillary tubes horizontally starting 6 in. (150 mm) from the bottom of the coil and spaced upwards 12 in. (300 mm). Each capillary tube is usually 20 ft (6.1 m) long.

2.4.10.2 Interlock the air handler's water coil freeze stat to initiate the following when 40°F (4°C) is detected:

A. Stop the blower.

B. Close all outside air dampers.

C. Open all return air dampers.

D. Open all valves serving chilled water or hot water coils inside the air handling unit.

E. Send an alarm to notify building managers.

2.4.10.3 Provide a drain pan under the water coils for inside air handling units and pipe the drain pan to a floor drain.

2.4.10.4 Provide a minimum 4-in. raised berm around interior air handling units with water coils. Seal the berm and floors and provide a floor drain for the sealed area.

2.4.11 Provide automatic de-icing systems on outside conveyors that are not totally enclosed.

2.5 Operation and Maintenance

2.5.1 Establish an asset integrity program in accordance with Data Sheet 9-0, *Asset Integrity*.

2.5.2 Ensure the building envelope is in good condition with no holes, cuts, or openings missing insulation and close unnecessary openings, especially doors and windows.

2.5.3 After making repairs, ensure all freeze protection including insulation is replaced. Consider a Management of Change tracking system as outlined in FM's Data Sheet 7-43, *Process Safety*.

2.5.4 Provide adequate fixed heat for areas where automatic wet-pipe sprinkler systems have frozen and ruptured during past cold weather events.

2.5.5 Maintain adequate depth of cover for underground fire service mains focusing where construction, excavation, erosion or freeze damage to mains has occurred. See Data Sheet 3-10, *Installation/Maintenance of Private Fire Service Mains and Their Appurtenances*, for recommended depth of cover and additional guidance on private fire service mains.

2.5.6 Maintain heating and heat tracing systems in accordance with the manufacturer's instructions. Complete all repairs prior to the on-set of cold weather.

2.5.7 Maintain HVAC systems according to the manufacturer's instructions. Prior to the onset of cold weather, test interlocks for air-handling units to initiate the following when 40°F (4°C) is detected:

A. Stop the blower.

B. Close all outside air dampers.

C. Open all return air dampers.

C. Open all valves serving chilled water or hot water coils inside the air handling unit.

D. Send an alarm to notify building managers.

2.5.8 When provided, maintain conveyor de-icing systems according to the manufacturer's instructions and test prior to the on-set of cold weather.

2.5.9 Train operators on standard and emergency operating procedures for freeze. See Data Sheet 10-8, *Operators*, for guidance on developing operator programs.

2.5.10 Maintain dry-pipes sprinkler systems as follows:

2.5.10.1 Check piping pitch for drainage of condensate to low-point drains and install more drains, if necessary.

2.5.10.2 Drain low points frequently.

2.5.10.3 Make sure the system is thoroughly drained after annual trip tests or any planned or unplanned activation.

2.5.10.4 Maintain and test air dryers if present.

2.5.11 Closely monitor temperatures of the coldest areas of sprinkler systems after several hours without heat when outside temperatures are below 20°F (-7°C). Pipe temperatures can also be monitored with an infrared thermometer.

2.5.12 When adequate heat is restored, inspect all water systems for breaks or ruptures. Turn each system on slowly and inspect for any leaks being prepared to quickly shut down the system if there are leaks. Leaks may occur since most systems cannot be fully drained.

2.6 Idle Facilities

Idle facilities are more susceptible to fire loss due to sprinkler systems being intentionally shut off to prevent freezing of pipes. In addition, a burning idle facility may threaten other functioning profit-making buildings nearby resulting in a business interruption loss.

Often, idle facilities are neglected and important services are shut off, including heat. They may get a cursory security glance every few days but often are not continuously monitored. This combination of factors makes them increasingly vulnerable to freeze.

2.6.1 Provide supervision and protection of property per Data Sheets 9-1, *Supervision of Property* and 10-6, *Arson and Other Incendiary Fires.*

2.6.2 Maintain a minimum of 40°F (4°C). If this is not possible or practical, convert wet-pipe fire protection systems to dry-pipe systems.

2.6.3 Keep automatic sprinklers in operation. In freezing temperatures, take the same precautions inside and outside the facility as are recommended for operating facilities. Continue to conduct weekly (and weekend) inspections of protection equipment.

2.6.4 Close all fire doors, elevators, and stairwell doors.

2.6.5 If possible, shut off electrical circuits at panels or switchgear.

2.6.6 Remove combustible contents from the building. Remove and isolate ignitable liquids. Disconnect and remove gas cylinders.

2.6.7 Maintain the outside of the facility. Repair broken windows and board up doors and other openings that are not in use.

2.6.8 If there are any on-site personnel, make sure they know how to implement the cold weather emergency plan.

2.7 Human Factor

2.7.1 Establish a freeze emergency response plan in accordance with Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*.

2.7.2 Provide annual training which includes full exercise of the freeze emergency response plan and ensure there are adequate supplies.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 FM Worldwide Freeze Map

The FM Worldwide Freeze Map identifies regions subject to a daily minimum temperature of 20°F (-6.7°C) or less on the 100-yr return period. The daily minimum temperature can be substantially lower than the daily mean temperature as mid latitude regions experience fluctuations in response to sudden cold air outbreaks. Laboratory and field experiments of pipe freezing suggest that the physical processes of freezing are complex and depend not only on temperature but also on pipe geometry, pipe material and piping insulation. Despite this complexity, the overwhelming majority of freezing incidents happen at the threshold of 20°F (-6.7 C). FM loss experience also correlates with this threshold. Therefore, a daily minimum temperature of 20°F (-6.7°C) is the threshold for application of this standard. Recommendations offered within this standard can be applied at higher 100-yr return period minimum temperature thresholds if desired.

3.2 Loss of Public Utilities can result in Freeze Damage

A building's envelope and heating system, along with fuel and power for the heating system, are the primary defenses against freeze damage inside buildings when outdoor air is 32°F or (0°C) or lower.

In extreme cold air outbreaks, public utilities can be impaired or lost leaving many facilities without building heat, steam and electricity for heat tracing to keep pumps and pipes from freezing and power for pumps used to circulate water to keep systems from freezing. Utilities can be impaired by ice storms that impact distribution systems, lack of freeze protection on power generation stations, inability for wind, solar and hydro generation to function, natural gas storage and delivery system freeze-ups, public water supply breakages, and/or cascading failures of multiple dependent utilities as seen in the 2021 Texas Deep Freeze event.

Outdoor equipment is particularly susceptible to freeze-ups. The probability of freeze-ups increases with lower ambient air temperature and increasing exposure time. Outdoor systems are inherently exposed to lower ambient temperatures over longer durations than indoor systems and should receive special care and attention.

3.2.1 Instrument Air

Instrument air is crucial for process control systems and water/condensation in the lines is susceptible to freezing and upsetting processes. This air needs to be dried to a pressure dew point at the dryer outlet that is 18°F (10°C) below the 100-year DMT. Desiccant type dryers may be needed to achieve lower dew points. See recommendation 2.4.6.

3.3 Process Freeze Hazard Analysis

There are many variables that effect the ability of fluids to freeze at a particular site; a detailed process freeze hazard analysis will help document the site's freeze design and protective layers to prevent freeze-up. This analysis will assist in identifying freeze vulnerabilities due to loss of site utilities, including electricity, natural gas, steam, nitrogen, potable water, etc. Recommendations for protection will arise during this hazard review and should be documented. This will also assist in management of future changes of the site and its freeze protection against climate risk. Recommendations that rely on human intervention should be documented in the site's freeze plan as outlined in FM's Data Sheet 10-1, *Pre-Incident and Emergency Response Planning.*

Factors that influence the freeze-up of pipes includes but is not limited to the following:

- Pipes of larger diameter have a larger volume and take a longer time to freeze.
- Pipes of various conductivity compositions affects the conductive heat loss through the pipe walls. However, if properly insulated, the effects of pipe composition on the freezing time are expected to be smaller as the conductive heat loss through the pipe walls is controlled by the insulation.
- A hot or cold water source has limited to no difference in the freezing process as the amount of supercooling and availability of ice nucleation is minimal.
- Wind chill (i.e., cold air moving across a warm surface) increases convective heat loss and has a greater cooling effect than still air, leading to faster freezing. However, wind chill only impacts uninsulated pipe. Thermal exchange factors on the outer boundary of insulated pipes are secondary and thus the convective heat losses are almost negligible.
- Insulation primarily slows the heat flux and conductive heat loss through the material or pipe walls and significantly slows freeze-ups. Pipe insulation alone will not prevent freeze damage if water is not moving.

3.4 Freeze Protection for Wet Pipe Sprinklers Above Suspended Ceilings with Restricted Airflow

Wet-pipe sprinklers above suspended ceilings that are adjacent to exterior walls where the airflow is restricted by construction features are especially vulnerable to freezing. Figure Fig. 3.4-1 shows a sprinkler line above a suspended ceiling that froze and ruptured leading to significant water damage. This occurred because the area was cut-off from the adjacent space above the suspended ceiling. The area above a suspended ceiling is usually indirectly warmed by the heated air in the occupied space below and thus will be cooler than the occupied area. Other negative factors included a double swinging door and full height glass windows on a north facing wall.

See recommendation 2.2.10 to protect wet pipe sprinklers in suspended ceilings.

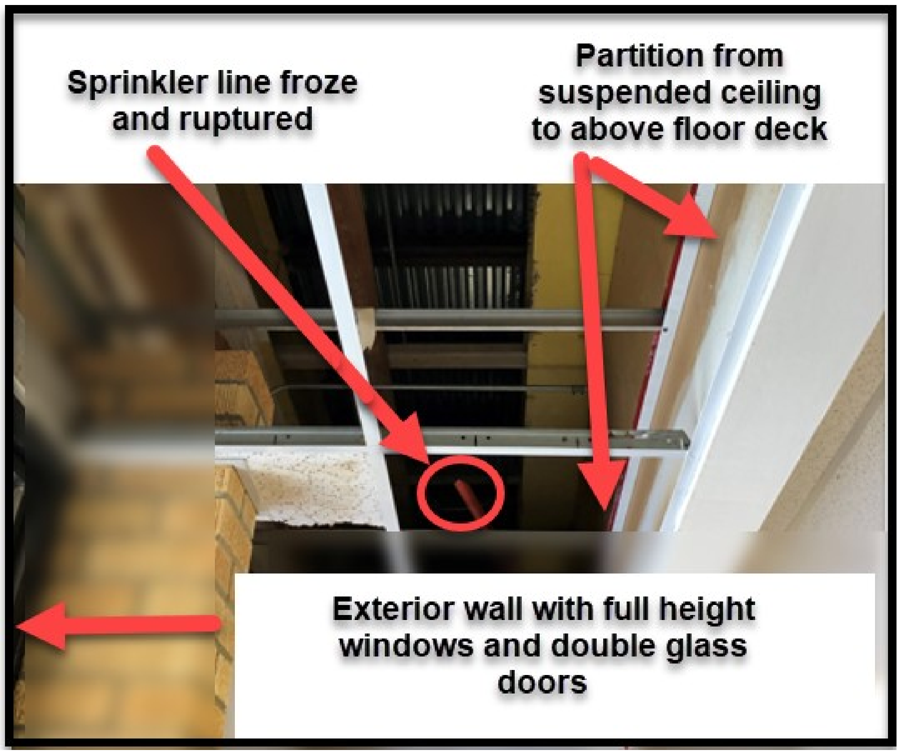

Fig. 3.4-1. Frozen/ruptured sprinkler line above suspended ceiling

3.5 Freeze Protection for Water Coils in Air Handling Units

During freezing temperatures, buildings may remain at normal temperatures but water-filled heat transfer coils in air handling units both outside and inside buildings can freeze, rupture and cause extensive water damage to the building (Figure 3.5-1, items 3 & 4).

This typically occurs when the outside air intake damper (Figure 3.5-1, item 1 and showing as closed) fails to close properly and the freeze-stat (Figure 3.5-2) and/or other controls fail to operate; coils and pipes freeze. The copper capillary tube (Figures 3.5-3 & 3.5-4) from the freeze-stat should be installed horizontally and attached to the back side of the water heat transfer coil shown in Figure 3.5-1, item 4.

Not all air handling units have water in heat transfer coils that can freeze. The air handling unit in Figure 3.5-1 has water in the heat transfer coil identified by the hot water piping (Figure 3.5-2) entering the unit. This unit also has a cooling coil (item 4 in Figure 3.5-1) known as a DX or direct expansion coil with refrigerant that won’t cause the coil to rupture.

Arrows in Figure 3.5-1 show the direction of airflow through the unit. Figure 3.5-1 item no. 3 is the front side, and item no. 4 is the back side of the water-filled heat transfer coil that can freeze.

Figure 3.5-1 item no. 2 is the recirculating air damper, shown as open, controlling the amount of recirculated air that is used. Failure of this damper to open when needed can lead to freeze damage.

See recommendation 2.4.10.1 to protect water heat transfer coils from freezing.

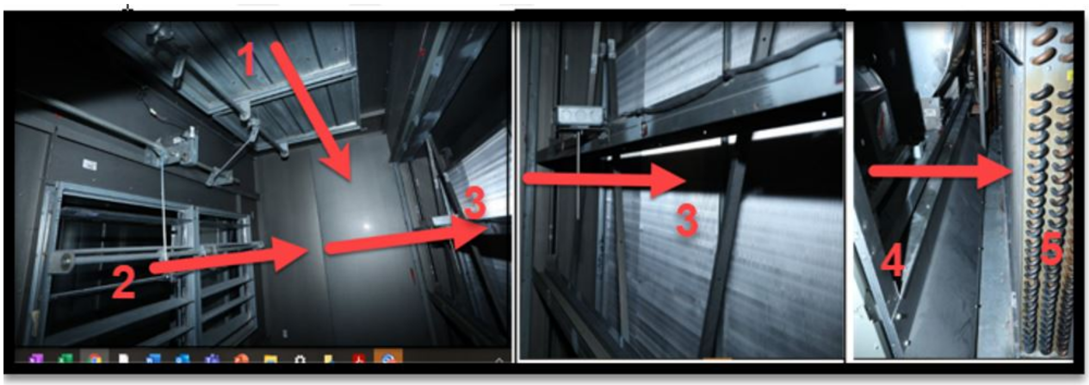

Fig. 3.5-1. Inside a typical air handling unit

Fig. 3.5-2. Water lines for the heat transfer coils

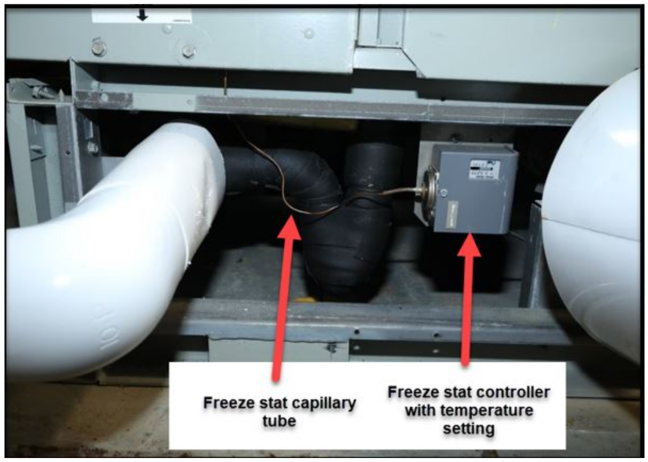

Fig. 3.5-3. Freeze stat controller and capillary tube with cover plate removed

Fig. 3.5-4. Continuation of the freeze stat's copper capillary tube inside the air handler

3.6 Loss History

A study of FM losses from 2012 through 2021 revealed that clients reported 3590 freeze-related incidents totaling US$2.174 billion. Incidents at non-manufacturing locations accounted for 87% of those losses by frequency and 42% by severity, with an average gross loss of US$545,000. Incidents at manufacturing locations accounted for 13% of freeze-related losses by frequency,58% by severity, average gross loss of US$1.3 million. All loss amounts are indexed to 2022 values.

3.7 Illustrative Losses

3.7.1 Freeze of Library Following Utility Outage

During a cold air outbreak, electricity to a university library was lost. The emergency power generator would not start due to frozen fuel and cooling supplies to the generator. This inhibited the movement of building heat throughout the library. A large open glass façade accelerated loss of building heat as electrical supplies remained impaired. Without building heat, the HVAC water lines and the fire sprinkler system froze and burst. This wetted over 250,000 books and 28,000 maps with many unsalvageable or requiring extensive restoration. The escaped water also wet interior carpeting and interior crevices with subsequent mold formation. Mold remediation and repairs closed the library for six weeks.

3.7.2 Failure to Analyze Process Change Results in Freeze at Chemical Plant

This metallurgical refinery produces alumina, a high-purity aluminum oxide, using the Bayer process. The process uses water-based caustic solutions to leach (digest) and refine mineral ores. A previous significant overpressure event on a digester at this refinery required a redesign of the pressure relief management system. The new system used of rotameters connected to vessels using water-filled sensing lines. When the pressure transmitters sense an increase in pressure, the system responds to shut off, empty, and isolate process vessels. When a pressure transmitter fails, the worst-case scenario is that an explosion may occur, while the best-case scenario is that mineral solutions may crystallize (harden) inside pipes and vessels.

Changes to the pressure relief system had been made without a commensurate management of change process. A process freeze hazard analysis had not been updated, and the negative effects of extended freezing temperatures on this system were not fully understood.

The site is located in a warm climate with infrequent cold air outbreaks. However, the facility uses heat tracing and steam to prevent product solidification including a steam loop inside the rotameter box.

Prior to the event, the National Weather Service predicted a serious freeze with nighttime temperatures dropping below freezing for several days. In fact, temperatures reached a low of 15° F (minus 9.4° C) with a wind chill of 0°F (-17.8° C). The plant's freeze plan was activated in response to the cold weather alert; this included a review of the heat tracing system and checks on steam flow for the rotameters. During the coldest night, the rotameters began to freeze, causing a cascading shutdown of all digesters and other process systems. The shutdown led to a loss of steam supply for the site and many vessels and piping systems lost heat tracing and freeze protection. Approximately 400 pipes ruptured causing cascading damage to other support areas of the site. When the steam heat was lost, the alumina mineral slurry in pipes and vessels hardened, requiring extensive and difficult removal.

The plant was shut down for several weeks and did not return to full production for three months.

3.7.3 A Series of Freeze Issues Impacted a Paper Mill

A full-process paper mill had two paper machines, batch digesters, recovery boiler, and lime kiln operations, producing on average 2,500 tons (2.27 kt) of paper per day.

The area experienced a major drop in air temperature. On Monday the low temperature was 11°F (-11.7°C); Tuesday 6°F (-14.4°C); and Wednesday 10°F (-12.2°C) with wind chills well below 0°F (-17.8°C). This caused multiple areas of the mill to sustain failures in instrumentation lines, which cascaded into several separate issues and there was difficulty keeping the entire operation running effectively.

At 1:42 p.m. on Monday, a pressure sensor on the natural gas line was recording errant readings due to crystallization in the 3/8 in. (10 mm) sensing line from the low temperatures. This forced the mill to shut down operations during repairs to prevent violating natural gas permits. After about 1 hour, the mill began the process of re-starting. However, it took much longer than normal to get the evaporators online due to the extreme cold temperatures and other frozen water lines, sensors, and operational controls that occurred while those lines were static.

About 10 hours later, the mill was just beginning to return to operation when the flow transmitter on the NCG line froze again despite the pressure and flow transmitters being insulated and heat-traced after the first incident. This shut down all mill operation progress again to thaw and repair the transmitter. This device was further insulated, heat-traced and put back online 9 hours later.

During the same time frame, low mill air pressure was reported (less than 65 psi [4.5 bar]). The air receiver units around three compressors had condensate freeze issues. This resulted in air-operated valves opening and closing too slowly or not operating. This was specifically determined to be the case for the dilution valve associated with the stock chest to one paper machine. With no water entering this area, heavy stock accumulated on one side of the chest wall, and eventually collapsed the wall due to the imbalance. This discovery was made several days after the collapse due to the lack of operation of the mill from all of the other issues. Once discovered, it took an extensive amount of time to remove and clean the stock chest. The debris from the collapse contaminated pulp in the high-density stock chest that fed both machines, and resulted in paper with spots throughout, indicative of contaminated pulp.

In addition, lack of movement of the conveyors and chip pile resulted in the chip pile freezing, causing large clumps of chips and the inability of the chips to dump onto the conveyor to be transported to the top of the digesters.

Meanwhile, with the digester and associated blow tank being static, a stock line froze and broke, resulting in heavy stock dumping onto the ground. This stock covered the nearest drain line that was directed to the strong liquor holding area, and instead found the next open drain line that sent the black liquor directly to the waste treatment pond. This overwhelmed the system completely and in turn created long-term challenges in getting the holding pond back to peak efficiency.

The mill had an agreement with local utilities to be cut off during peak demand periods. Due to the extreme weather event, this was called by the local utility on both gas and electricity. However, because there was no production of black liquor, the recovery boiler was running on oil alone and could not keep up with the steam demand required to run the turbines.

One paper machine incurred 7 days of downtime or poor quality production and the other was down for 5 days of production or poor quality issues.

Extreme temperatures resulted in instrumentation freezes of items that had never been reported to be a winterization issue in the past.

Positive factors:

- An extensive winterization plan had been created and many actions were taken to protect the mill during this type of harsh winter weather.

Negative factors:

- Continuous cold weather several days in a row did not allow the plant to recover during the day and prepare for the following night.

3.7.4 Burst Pipes Near Exterior Walls Damage High Value Areas in a Hospital

This loss occurred at a group of multi-story hospital buildings with basements. The 8-story main hospital had reinforced concrete floors and walls, while the 4-story concentrated care building had a protected steel frame structure with concrete on metal deck floors and masonry walls.

The affected areas were located against exterior walls. The areas were fully sprinklered, with piping in unheated spaces above the mineral tile ceilings.

Severe cold weather gripped the area in the days preceding the incident. This extended cold spell, along with high winds, caused sprinkler piping in three areas of the hospital to freeze. Damaged piping was primarily limited to 1 in. (25 mm) diameter pipe, elbows, and tees and a cross main. The loss was exacerbated because of high value or sensitive areas below the breaks or on lower levels, such as: operating rooms, an auditorium, a pharmacy, a data center, and a sterilization area.

Damage consisted of wet-down floor tiles, carpeting, and drywall (walls and ceilings). Servers in the data center, pharmacy drugs, and sterilized surgical instruments were wetted.

A number of surgeries were canceled or postponed. Damage to the data center resulted in sending lab tests off-site for processing. Pharmacy retail sales were affected for a few days.

Positive factors:

- Prompt discovery and action by hospital personnel helped to mitigate exposed areas and damage.

Negative factors:

- Improper insulation on the inside surface of exterior walls allowed cold temperatures to penetrate the building envelope.
- Improper heat in areas above the suspended ceilings allowed cold temperature to freeze sprinkler piping.
- High-value occupancies were located in basements.

4.0 REFERENCES

4.1 FM

Data Sheet 1-45, *Air Conditioning and Ventilation Systems*
Data Sheet 1-54, *Roof Loads and Drainage*
Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*
Data Sheet 2-81, *Fire Protection, Safety Inspection, Testing and Maintenance*
Data Sheet 3-2, Water Tanks for Fire Protection
Data Sheet 3-4, *Embankment-supported Fabric Tanks*
Data Sheet 3-6, *Lined Earth Reservoirs or Fire Protection.*
Data Sheet 3-7, *Fire Protection Pumps*
Data Sheet 3-10, *Installation/Maintenance of Private Fire Service Mains and Their Appurtenances*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 9-1, *Supervision of Property*
Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*
Data Sheet 10-3, *Hot Work Management*
Data Sheet 10-6, *Protection Against Arson and Other Incendiary Fires*
Data Sheet 10-7, *Fire Protection Impairment Management*
Data Sheet 10-8, *Operators*

Freeze-Up Checklistmed (P9521)
Freeze Emergency Response Plan (F7650)
UTH: *Freeze* (P0148)
UTH: *Idle, Vacant or Strikebound Facilities* (P0274)
Protecting Your Facilities from Winter Storms (P0101)

4.2 Other

American National Standards Institute/Instrument Society of America. ANSI/ISA-S7.0.01. *Quality Standard for Instrument Air*.

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). ASHRAE 90.1-2019 (I-P), *Energy Standard for Buildings Except Low-Rise Residential Buildings*.

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). ASHRAE 90.2-2018, *Energy Efficient Design of Low-Rise Residential Buildings*.

National Fire Protection Association (NFPA) NFPA 13R Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies.

APPENDIX A GLOSSARY OF TERMS

FM Approved: Products and services that have satisfied the criteria for Approval by FM Approvals. Refer to the *Approval Guide* for a complete list of products and services that are FM Approved.

Freeze-prone area: Locations where the 100-year return period daily minimum temperature (100-year DMT) is 20°F (-6.7°C) or colder as shown in the FM Worldwide Freeze Map, available online at www.fmglobal.com.

Supervision: See Data Sheet 9-1, *Supervision of Property*.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

July 2022. Full revision. The following significant changes were made:

A. Clarified existing and added new recommendations for locations where the 100-year return period daily minimum temperature (100-year DMT) is 20°F (-6.7°C) or colder as shown in the FM Worldwide Freeze Map, available online at www.fmglobal.com.

B. Replaced freeze maps and tables in Appendix D with an overview map of freeze areas.

July 2021. Interim revision. Moved guidance on emergency response planning to Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*. Also made minor editorial changes.

April 2016. The following major changes were made.

A. Defined where the data sheet is applicable.

B. Added maps of lowest one-day mean temperature and 5°F (-15°C) record low temperature.

C. Revised Appendix C; much of the design information for heat-tracing was deleted.

D. Added Appendix D to indicate freeze-prone areas by country.

January 2007. Corrections were made to Appendix B, Document Revision History.

May 2003. Revised section "3.1 Loss History".

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

APPENDIX C SUPPLEMENTARY INFORMATION

C.1 Heat Tracing Systems

C.1.1 Electrical Resistance Heat Tracing Systems

An electrical heat tracing system is designed to prevent freezing in process piping and control systems. It consists of resistance type heater cables permanently fastened to the process pipe. The equipment can maintain specific temperatures by the use of a temperature-regulating controller.

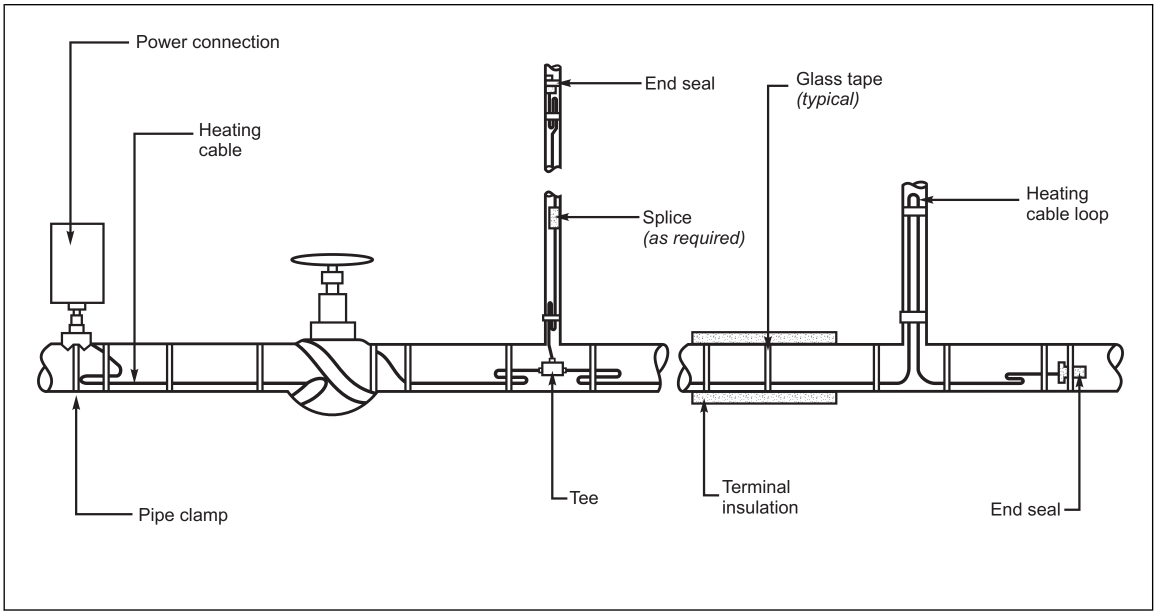

Fig. C.1.1-1. Typical heat tracing system

The design of the heat tracing should include a tracing schedule. The schedule should list all heat tracer routing drawings. The schedule should be a permanent drawing kept in reproducible form so that it may be updated to reflect modifications made during construction or operations.

For complex systems using electrical or circulating fluid tracing, an analogous tracing schedule should be made. For simple systems, it may be enough to show the tracing on flow or wiring diagrams or layouts.

C.1.2 Self-Regulating Electric Heating Cables

Self-regulating heating cables are unique in that they feature a core of conductive carbon and polymers that are temperature sensitive. The polymers sense the temperature of the pipe and provide power output inversely proportional to the pipe's temperature, without the need for manual adjustment. Automated monitoring and control systems with self-regulating electric heating cable enable, industries to economically and reliably maintain process pipe temperatures to prevent freezing and keep process liquids flowing.

The variety of electrical heat tracing systems available has increased the number of applications, making them a viable option for protecting pipes in many types of industry.

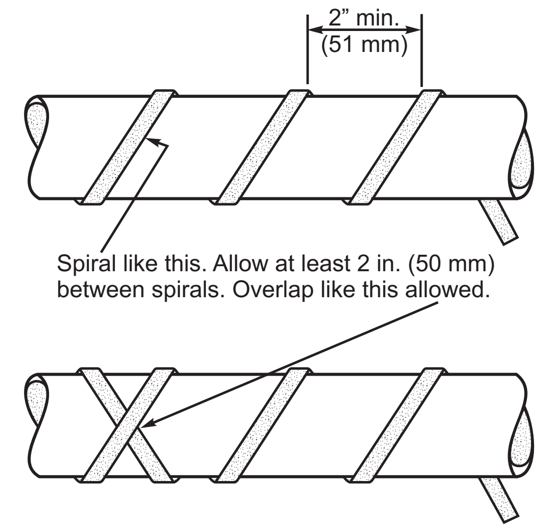

Fig. C.1.2-1. Installation of self-regulating heating cable

C.1.3 Steam Jacketing

Steam jacketing consists of outer and inner pipes with steam circulating between them. It is one of the oldest, and formerly the most widely used method of heating a line, particularly for high heating loads. While the heat transfer characteristics of this system are good, installation and repair costs are extremely high. This section of pipe (see Figure C.1.3-1) is shown ready for testing of internal welds (at left); jacket-fitting pieces welded to the jacketed pipe complete the assembly (at right).

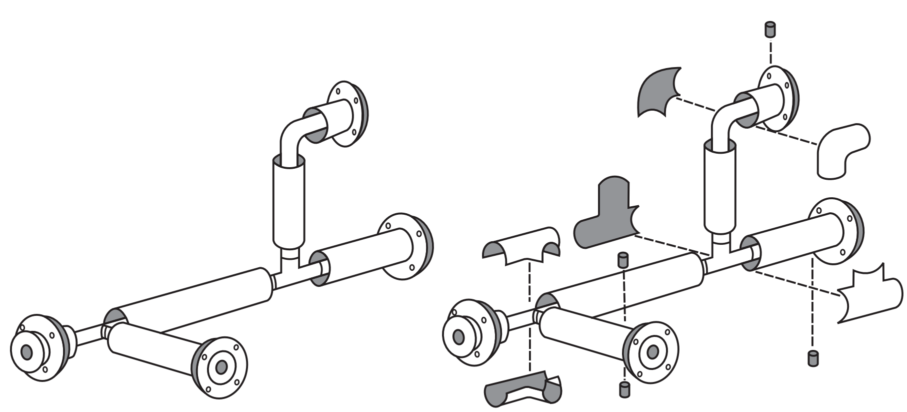

Fig. C.1.3-1. Prefabricated jacketed section

C.1.4 Internal Steam Tracing Systems

Internal steam tracing consists of a steam tracer running through the center of the pipe. An important disadvantage of this method is that the pipe cannot be cleaned with scrapers or rigs. Although internal tracing is less costly than steam jacketing and has better heat-transfer characteristics than external tracing, it also presents the possibility of contamination.

Flow area in the process line is reduced because of the space occupied by the tracer. Flow area is further reduced by accumulations on the relatively cooler outside wall. The result of both factors is a process line larger than what would be required if they were applied externally. In certain processes, the internal tracer should be constructed of an alloy that will resist the corrosiveness of process fluids. An example of this is caustic soda in concentration of 50% or higher.

The expansion and contraction of both the internal and the more conventional external tracers cause a constant flexing of metal that is the source of many failures from metal fatigue. Leakage from internal tracing can also lead to costly downtime.

A fast heating-up rate and low cost are the advantages of internal tracing. Its disadvantages are the possibility of contamination, a reduced flow area and uneven temperature distribution.

C.1.5 External Steam Tracing Systems

If passive prevention of heat is not enough, then external steam tracing or heating of the piping from outside may be necessary. Heavy-oil fuel lines, instrument-air lines, drain lines, and chemical lines are the most common applications in various types of plants. Some typical applications of steam tracers are shown in Figures C.1.5-1 and C.1.5-2. Steam tracing is one or more small-bore lines run close to the process or instrument lines and may be enclosed in the insulation as a part of the piping system.

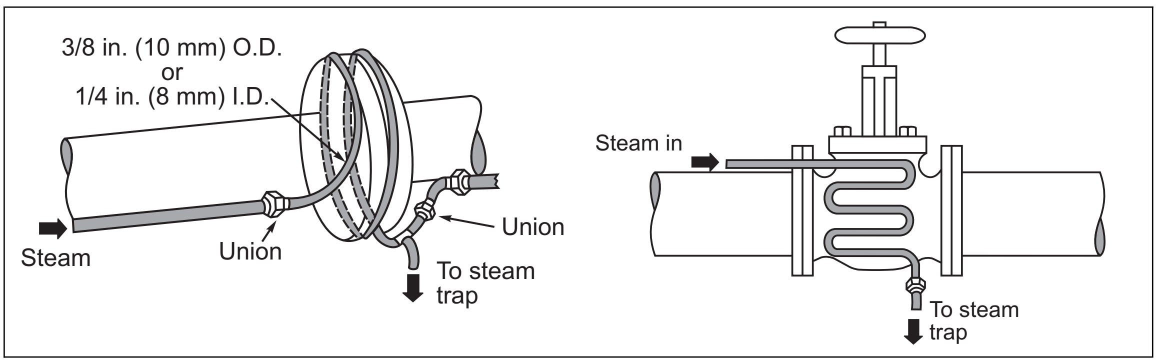

Fig. C.1.5-1. Steam tracer on a flange, on a straight pipe and a valve

Single-line steam tracing consists of tubing attached parallel to the pipes. Both are insulated and covered with a weatherproof jacket. Steam under pressure is supplied to one end of the tubing, with condensate removal from the other. Success depends upon careful attention to sound principles and details in design; careful and skilled workmanship in construction; meticulous inspection and testing before the insulation is applied; and simple conscientious maintenance.

Bundles with two, three or four 3/8-in. (10 mm) outside diameter tubes are also occasionally used for steam supply and condensate collection lines. Bundles with two 3/8-in. (10 mm) copper tubes and one 1/2-in. (13 mm) stainless steel tube are also useful for tracing instrument impulse lines, so that the same bundle can be used for steam tracing and condensate return.

Use of the pre-insulated bundles greatly reduces the amount of labor and inconvenience in handling loose insulation materials, and the bundles are particularly advantageous in maintenance work since the tracers are almost immediately accessible.

Another method of using steam tracing, specifically for instrument freeze-up protection, is the use of steam studs in place of one or two of the standard flange bolts and nuts. See Figure C.1.5-3. A steam stud is essentially a hollow bolt made of corrosion-resistant, high strength material. Steam is passed through these

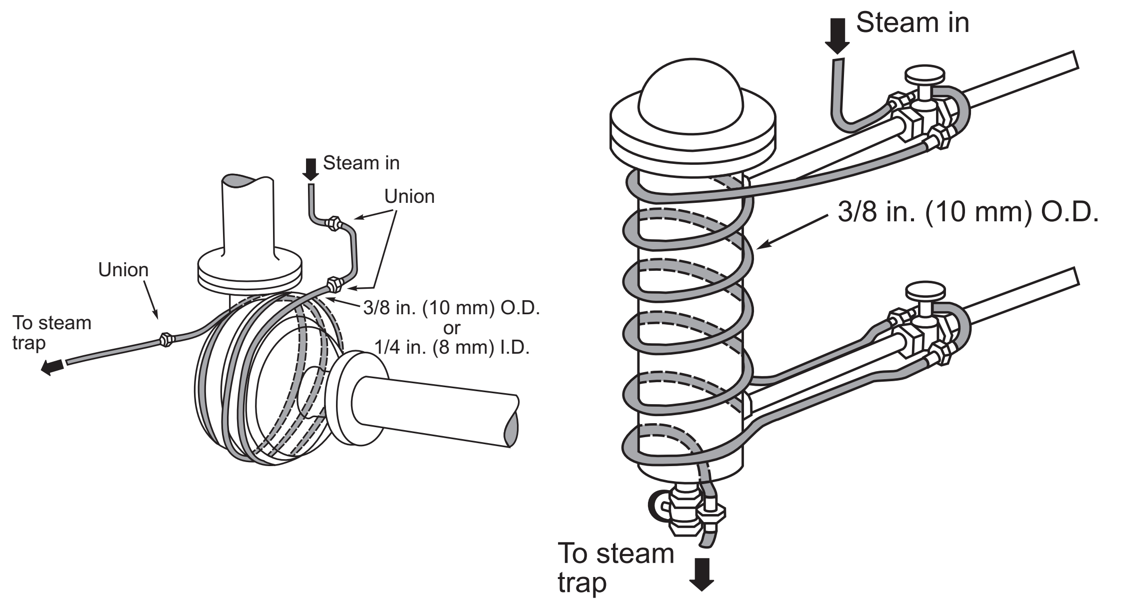

Fig. C.1.5-2. Steam tracer lines around pump casing and typical instrument tracing

studs to provide the necessary heat to the instrument housing. Depending upon the ambient conditions, an insulated box may also be required. Never, however, should more than two steam studs be used on each instrument housing.

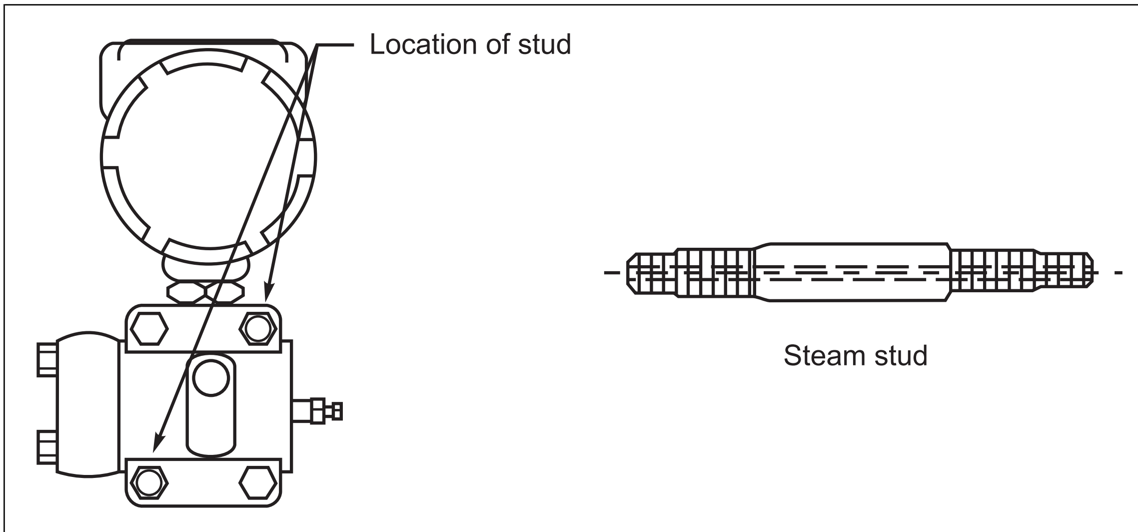

Fig. C.1.5-3. Steam stud arrangement

C.1.6 Insulation

Thermal insulating materials and application methods are well known in the pulp and paper and process industries. Where atmospheric temperatures are always above the freezing point of the fluids handled, insulation is usually applied only to conserve heat energy or to protect operating personnel against burns.

However, where ambient temperatures can drop below the freezing point of any of the fluids in the plant, provide insulation for equipment, instruments, pipelines and instrument lines that could otherwise be uninsulated. While sub-freezing temperatures may occur only a few nights each winter, unless the plant is properly protected and operated, freeze-ups could cause costly shutdowns, property damage and business interruption.

C.1.7 Advantages and Disadvantages of Various Heat Tracing Systems

Choosing the best method of heat tracing for a particular plant or a particular area within a plant requires careful analysis of process constraints and ambient conditions as well as economics and system reliability. The analysis should include the following considerations:

A. Steam systems can be readily adjusted to compensate for unusually cold weather by raising the pressure. One would need a variable frequency device to do the same for electrical tracing.

B. Electrical heating systems are less expensive to install, but steam heat is less expensive to operate if there is steam already used in the process which can be used also for tracing.

C. When both systems receive the same level of economical maintenance, the steam system may be about as reliable as the electrical.

D. While steam presents a contamination exposure, electrical tracing presents a fire exposure.

APPENDIX D FREEZE AREA

An overview of FM’s Worldwide Freeze Map is shown in Figures D-1 and D-2. More detail and 100-year DMT’s for freeze areas are available online at www.fmglobal.com. Non-white areas are freeze areas where the 100-year DMT’s are 20°F (-6.7°C) or less.

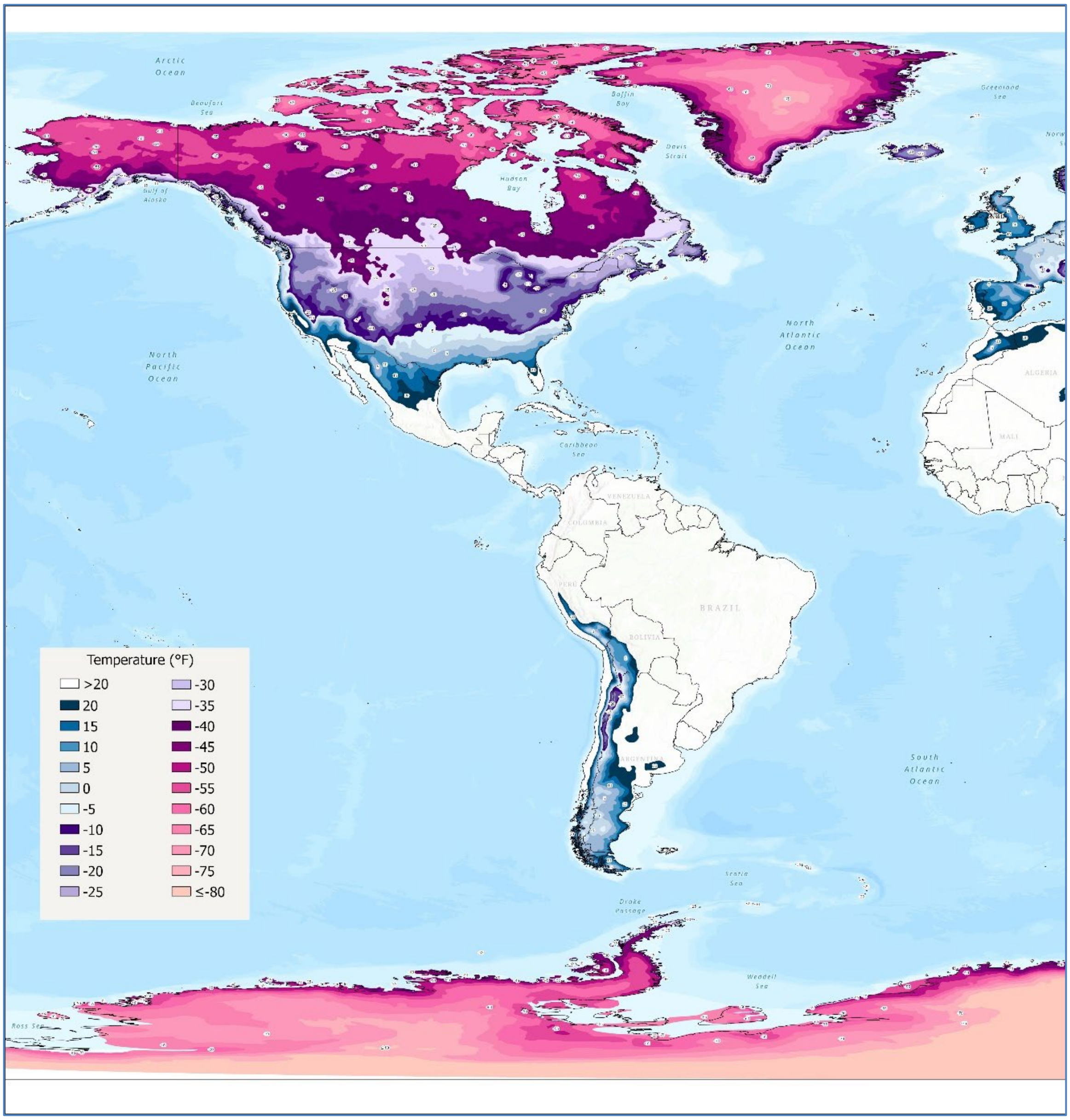

Fig. D-1. Freeze areas: Western Hemisphere

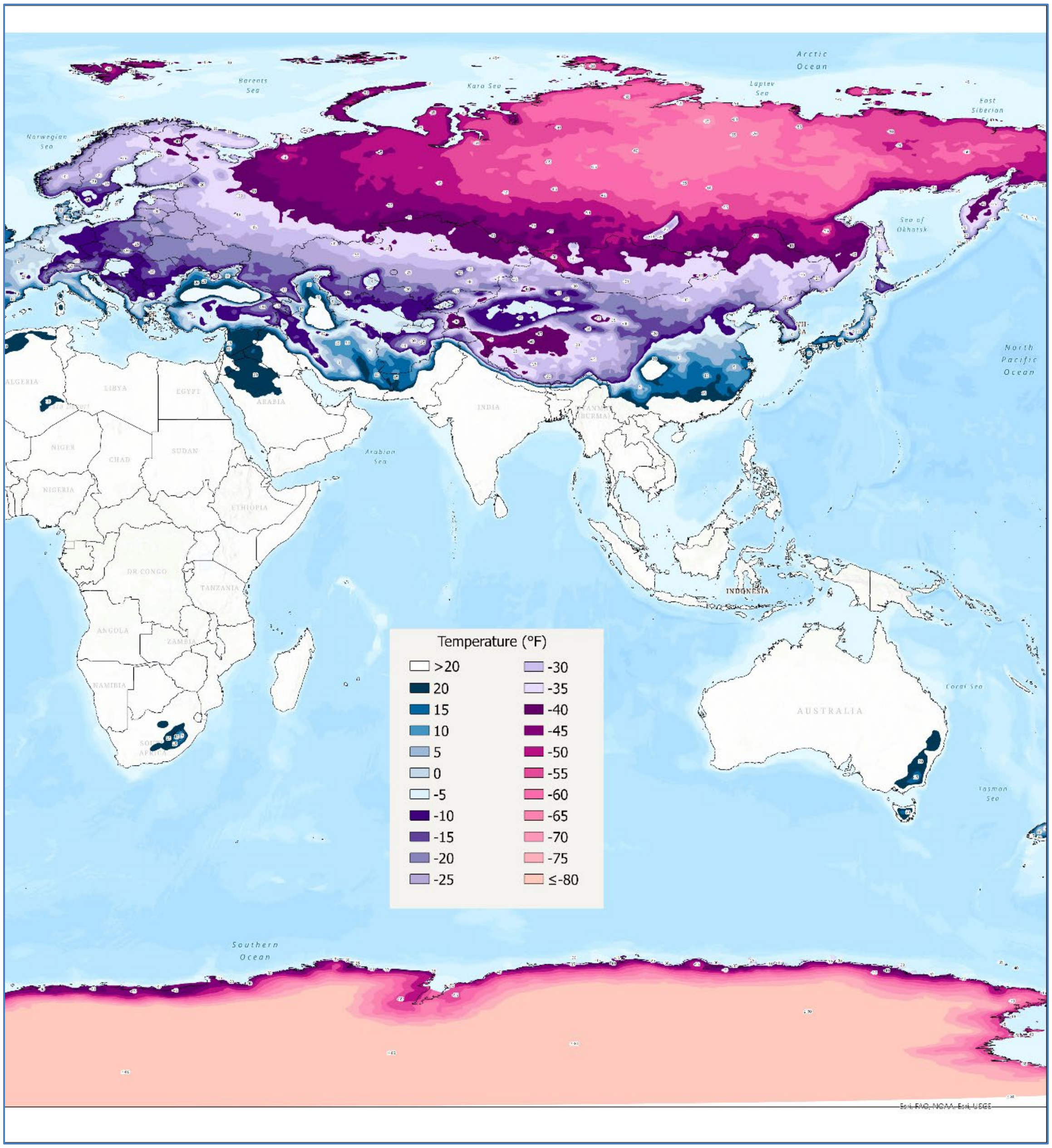

Fig. D-2. Freeze areas: Eastern Hemisphere