

INSULATION SYSTEMS FOR REFRIGERANT PIPING

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THIS chapter is a guide to specifying insulation systems for refrigeration piping, fittings, and vessels operated at temperatures ranging from 2 to -70°C . It does not deal with HVAC systems or applications such as chilled water systems. Refer to [Chapters 23, 24, and 25 in the ASHRAE Handbook—Fundamentals](#) for information about insulation and vapor barriers for these systems.

The success of an insulation system for cold piping, such as refrigerant piping, is contingent on such factors as the following:

- Correct refrigeration system design
- Correct specification of insulating system
- Correct specification of insulation thickness
- Correct installation of the insulation and related materials such as vapor retarders
- Quality of the installation
- Adequate maintenance of the insulating system

A variety of insulation materials are used for HVAC, steam, and hot-water lines that either run hot or cycle between cold and hot. These lines are insulated for the following reasons:

- Energy conservation
- Economics (to provide the minimum annualized costs of ownership and operation)
- External surface condensation control
- Prevention of gas condensation inside the pipe
- Process control (i.e., for freeze protection and to limit temperature change of process fluids)
- Personnel protection
- Fire protection
- Sound and vibration control

The design features for typical refrigeration insulation applications recommended in this chapter may be followed unless they conflict with applicable building codes. A qualified engineer may be consulted to specify both the insulation material and the insulation thickness (see [Tables 2 through 11](#)) based on specific design conditions. All fabricated pipe, valve, and fitting coverings should have dimensions and tolerances in accordance with ASTM *Standards* C585 and C450. The installation of all materials used for thermal insulation should be carried out in accordance with the Midwest Insulation Contractors Association's (MICA) National Commercial and Industrial Insulation Standards or the recommendations of the manufacturers for materials not presented in this standard.

DESIGN CONSIDERATIONS FOR BELOW-AMBIENT REFRIGERANT PIPING

Below-ambient refrigerant lines are insulated primarily to (1) minimize heat gain to the internal fluids, (2) control surface condensation, and (3) prevent ice accumulations. Noise reduction and personnel protection are also reasons for providing thermal insulation. For

most installations, the thickness required to prevent surface condensation will control the design. Given appropriate design conditions and insulation properties, available computer programs such as NAIMA 3E Plus may be helpful in calculating the required insulation thickness. [Tables 3 through 12](#) give estimates for several typical design conditions for a variety of insulation materials.

In many refrigeration systems, operation is continuous; thus, the vapor drive is unidirectional. Water vapor that condenses on the pipe surface or in the insulation remains there (as liquid water or as ice) unless removed by other means. An insulation system must deal with this unidirectional vapor drive by providing a continuous and effective vapor retarder to limit the amount of vapor entering the insulation.

A variety of insulation and accessory materials are used in systems for refrigerant piping. The successful system design provides the best solution for material selection, installation procedures, operations, and maintenance to achieve long-term satisfactory performance, meeting all criteria imposed by the owner, the designer, and code officials.

INSULATION PROPERTIES AT BELOW-AMBIENT TEMPERATURES

Insulation properties important for the design of below-ambient systems include thermal conductivity, water vapor permeance, water absorption, coefficient of thermal expansion, and wicking of water. See [Table 2](#) for material properties.

Thermal conductivity of insulation materials varies with temperature, generally decreasing as temperature is reduced. For pipe insulation, conductivity is determined by ASTM *Test Method* C335. This method is generally run at above-ambient conditions and the results extrapolated for below-ambient applications. In some cases, conductivity is determined on flat specimens (using ASTM *Test Method* C177 or *Test Method* C518). The designer should be aware of the method used and its inherent limitations.

Water vapor permeance is a measure of the time rate of water vapor transmission through a square foot of material or construction induced by a unit vapor pressure difference through two specific surfaces, under specified temperature and humidity conditions. The lower the permeance, the higher is the resistance of the material or system to passing water vapor. The unit of water vapor permeance is the perm, and data are determined by ASTM *Test Method* E96. Like thermal conductivity, permeance can vary with conditions. Data for most insulation materials are determined at room temperature using the "desiccant method." Water vapor permeance can be critical in design because water vapor can penetrate materials or systems that are unaffected by water in the liquid form. Water vapor diffusion is a particular concern to insulation systems subjected to a thermal gradient. Pressure differences between ambient conditions and the colder operating conditions of the piping drive water vapor into the insulation. There it may be retained as water vapor, condense to liquid water, or condense and freeze to form ice, and can eventually cause the insulation to "pop off" the pipe. Thermal properties of

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insulation materials are negatively affected as the moisture or vapor content of the insulation material increases.

The coefficient of thermal expansion is important both for insulation systems that operate continuously at below-ambient conditions and systems that cycle between below-ambient conditions and elevated temperatures. Thermal contraction of insulation materials may be substantially different from that of the metal pipe. A large difference in contraction between the insulation and the piping may open joints in the insulation, which not only create a thermal short circuit at that point, but may also affect the integrity of the entire system. Insulation materials that have large coefficients of thermal expansion and do not have a high enough tensile or compressive strength to compensate may experience shrinkage and subsequently crack. At the high-temperature end of the cycle, the reverse is a concern. High thermal expansion coefficients may cause warping or buckling that is permanent for some insulation material. In this instance, the possible stress on an external vapor retarder or weather barrier should be considered.

Water absorption is the ability of a material to absorb and hold liquid water. Water absorption is important where systems are exposed to water. This water may come from a number of external sources such as rain, surface condensation, or washdown water. The property of water absorption is especially important on outdoor systems and when vapor retarder or weather retarder systems fail. Collected water in an insulation system degrades thermal performance, enhances corrosion potential, and will shorten the service life of the system.

Wicking is the tendency of an insulation material to absorb liquid due to capillary action. Wicking is measured by partially submerging a material and measuring both the mass of liquid that is absorbed and the volume that the liquid has filled within the insulation material.

Insulation System Water Resistance

Refrigeration systems are often insulated to conserve energy and prevent surface condensation. An insulation system's resistance to the intrusion of water is a critical consideration for many refrigerant piping installations. When the vapor retarder system fails, water vapor will move into the insulation material. This may lead to partial or complete failure of the insulation system. The problem becomes more severe at lower operating temperatures and when operating continuously at cold temperatures. The driving forces are greater in these cases and water vapor will condense and freeze on or within the insulation. As more water vapor is absorbed, the thermal conductivity of the insulation material increases, which leads to a lower surface temperature. This lower surface temperature leads to more condensation, which may cause the insulation material to pop off due to ice formation. With refrigeration equipment operating at 2°C or lower, the problem may be severe.

If a low-permeance vapor retarder is properly installed on the insulation system and is not damaged in any way, then the water resistance of the insulation material is not as important. In practice, it is very difficult to achieve and maintain perfect performance in a vapor retarder. Therefore, the water resistance of the insulation material is an important design consideration. The water absorption and water vapor permeability properties of an insulation material are good indicators of its resistance to water. Because intrusion of water into an insulation system has numerous detrimental effects, better long-term performance can be achieved by limiting this intrusion. For these reasons, insulation materials with high resistance to moisture (low absorption and permeability) should be used for refrigerant piping operating at temperatures below 2°C.

THE INSULATION SYSTEM

The elements of a below-ambient temperature insulation system include

- Pipe preparation
- Insulation material

- Insulation joint sealant/adhesive
- Vapor retarders
- Weather barrier/jacketing

Pipe Preparation for Corrosion Control

Before any insulation is applied, all equipment and pipe surfaces to be insulated **must** be dry and clean of contaminants and rust. Corrosion of any metal under any thermal insulation can occur for a variety of reasons. The outer surface of the pipe should be properly prepared before the installation of the insulation system. The pipe can be primed to minimize the potential for corrosion. Careful consideration at the time of the insulation system design stage is essential. The prime concern is to keep the piping surface dry throughout its service life. A dry, insulated pipe surface will not have a corrosion problem. Wet, insulated pipe surfaces are the problem.

Insulated carbon steel surfaces that operate continuously below -5°C do not present major corrosion problems. However, equipment or piping operating either steadily or cyclically at or above these temperatures may have significant corrosion problems if water or moisture is present. These problems are aggravated by inadequate insulation thickness, improper insulation material, improper insulation system design, and improper installation of insulation.

Common flaws include the following:

- Incorrect insulation materials, joint sealants/adhesives or vapor retarders used on below-ambient temperature systems
- Improper specification of insulation materials by generic type rather than by specific material properties required for the intended service
- Improper or unclear application methods

Carbon Steel. Carbon steel corrodes not because it is insulated, but because it is contacted by aerated water and/or a waterborne corrosive chemical. For corrosion to occur, water must be present. Under the right conditions, corrosion can occur under all types of insulation. Examples of insulation system flaws that create conditions that may promote corrosion include

- Annular space or crevice for the retention of water
- Insulation material that may wick or absorb water
- Insulation material that may contribute contaminants that can increase the corrosion rate

The corrosion rate of carbon steel depends on the temperature of the steel surface and the contaminants in the water. The two primary sources of water are infiltration of liquid water from external surfaces and condensation of water vapor on cold surfaces.

Infiltration occurs when water from external sources enters an insulated system through breaks in the vapor retarder or breaks in the insulation itself. The breaks may be the result of inadequate design, incorrect installation, abuse, or poor maintenance practices. Infiltration of external water can be reduced or prevented.

Condensation results when the metal temperature or the insulation surface temperature is lower than the dew point. Insulation systems cannot always be made completely vaportight, so condensation must be recognized in the system design.

The main contaminants found in insulation are chlorides and sulfates, introduced during the manufacture of the insulation or from external sources. These contaminants may hydrolyze in water to produce free acids, which are highly corrosive.

Table 1 lists a few of many protective coating systems that can be used for carbon steel. For other systems or for more details, contact the coating manufacturer.

Copper. External stress corrosion cracking (ESCC) is a type of localized corrosion of various metals, notably copper. For ESCC to occur in a refrigeration system, the copper must undergo the combined effects of sustained stress and a specific corrosive species. During ESCC, copper degrades so that localized chemical reactions

Table 1 Protective Coating Systems for Piping

Substrate	Temperature Range	Surface Prep. ^d	Surface Profile	Prime Coat ^a	Intermediate Coat ^a	Finish Coat ^a
Carbon Steel System No.1	−45 to 60°C	NACE No. 2	50 to 75 μm	125 μm high-build (HB) epoxy	N/A	125 μm HB epoxy
Carbon Steel System No.2	−45 to 60°C	NACE No. 2	50 to 100 μm	180 to 250 μm metallized aluminum	13 to 20 μm of MIL-P-24441/1 ^b epoxy polyamide (EPA) followed by 75 μm of MIL-P-24441/1 ^c EPA	75 μm of MIL-P-24441/2 ^c EPA
Carbon Steel System No.3	93°C max.	NACE No. 2	50 to 75 μm	50 to 75 μm moisture-cured urethane aluminum primer	50 to 75 μm moisture-cured micaceous aluminum	Two 75 μm coats of acrylic urethane
Carbon Steel System No.3	−45 to 150°C	NACE No. 2	50 to 75 μm	150 μm epoxy/phenolic or high-temperature rated amine-cured coal tar epoxy	N/A	150 μm epoxy/phenolic or high-temperature rated amine-cured coal tar epoxy

^a Coating thicknesses are typical dry film values.

^b General Specification for Epoxy-Polyamide Paint. MIL-P-24441, Part 1.

^c General Specification for Epoxy-Polyamide Paint. MIL-P-24441, Part 2.

^d NACE No. 2/SSPC-SP 10, Near-White Metal Blast Cleaning. Standard of the National Association of Corrosion Engineers International, Houston, TX and Steel Structures Painting Council, Pittsburgh, PA.

occur, often at the grain boundaries in the copper. The localized corrosion attack creates a small crack that advances under the influence of the tensile stress. The common form of ESCC (intergranular) in copper results from grain boundary attack. Once the advancing crack extends through the metal, the pressurized refrigerant leaks from the line.

ESCC occurs in the presence of the following four conditions:

- The presence of oxygen (air)
- The presence of tensile stress, either residual or applied. In copper, stress can be put in the metal at the time of manufacture (residual) or during installation (applied) of a refrigeration system.
- The presence of a chemical corrosive
- The presence of water (or moisture) to allow the copper corrosion process to occur

The following precautions reduce the risk of ESCC in refrigeration systems:

- Properly seal all seams and joints of the insulation to prevent condensation between the insulation and the copper tubing.
- Avoid introducing applied stress to copper during installation. Applied stress can be caused by any manipulation, direct or indirect, that stresses the copper tubing; for example, applying stress to align a copper tube with a fitting or physically damaging the copper prior to installation.
- Never use chlorinated solvents such as 1,1,1-trichloroethane to clean refrigeration equipment. Such solvents have been linked to rapid corrosion.
- Use no acidic substances such as citric acid or acetic acid (vinegar) on copper. Such acids are found in many cleaners.
- Make all soldered connections gastight because a leak could cause the section of insulated copper tubing to fail. A gastight connection prevents self-evaporating lubricating oil, and even refrigerants, from reacting with moisture to produce corrosive acidic materials such as acetic acid.
- Choose the appropriate thickness of insulation for the environment and the operating condition to avoid condensation on the copper tubing.
- Never mechanically constrict or adhere the insulation to the copper. An example of mechanical constriction is the use of wire ties to compress the insulation. This operation may result in the pooling of water between the insulation and the copper tubing.
- Prevent extraneous chemicals or chemical-bearing materials such as corrosive cleaners containing ammonia and/or amine salts, wood smoke, nitrites, and ground or trench water, from contacting the insulation or copper.
- Prevent water from entering between the insulation and the copper. Where the layout of the system is such that condensation may

form and run along uninsulated copper by gravitational force, completely adhere and seal the beginning run of insulation to the copper or install vapor stops.

- Use copper that complies with ASTM *Standard* B280. Buy copper from a reputable manufacturer.
- When pressure testing copper tubing, take care not to exceed the specific yield point of the copper.
- When testing copper for leaks, use only a commercial refrigerant leak detector solution specifically designed for that purpose. Assume that all commercially available soap and detergent products contain ammonia or amine-based materials, all of which contribute to the formation of stress cracks.
- Replace any insulation that has become wetted or saturated with refrigerant lubricating oils. Such oils can react with moisture to form corrosive materials.

Stainless Steel. Certain grades of stainless steel piping are susceptible to ESCC. ESCC occurs in austenitic steel piping and equipment when chlorides in the environment or insulation material are transported in the presence of water to the hot surface of stainless steel and are then concentrated by evaporation of the water. This situation occurs most commonly beneath thermal insulation, but the presence of insulation is not a requirement. Thermal insulation simply provides a medium to hold and transport the water with its chlorides to the metal surface.

Most ESCC failures occur when the metal temperature is in the hot-water range of 50 to 150°C. Failures are less frequent when the metal temperature is outside of this range. Below 50°C the reaction rate is slow and the evaporative concentration mechanism is not significant. Equipment that cycles through the water dew-point temperature is particularly susceptible. Water that is present at the low temperature evaporates at the higher temperature. During the high-temperature cycle the chloride salts dissolved in the water concentrate on the surface.

As with copper, in order for ESCC to develop, sufficient tensile stress must be present in the stainless steel. Most mill products, such as sheet, plate, pipe, and tubing, contain enough residual processing tensile stresses to develop cracks without additional applied stress. When stainless steel is used, coatings may be applied to prevent ESCC. A metallurgist should be consulted to avoid catastrophic piping system failures.

Insulation Materials

All insulation must be stored in a cool, dry location and be protected from the weather before and during application. Vapor retarders and weather barriers must be installed over dry insulation. The insulation system should have a low thermal conductivity with low water vapor permeability.

Table 2 Properties of Insulation Materials

	Cellular Glass	Flexible Elastomeric	Closed-Cell Phenolic	Polyisocyanurate	Polystyrene
Standard that specifies material and temperature requirements	ASTM C552	ASTM C534	ASTM C1126	ASTM C591	ASTM C578
Suitable temp. range, °C	–270 to 430	–30 to 104	–180 to 120	–183 to 150	–55 to 75
Flame spread rating ^a	5	25	25	25	25
Smoke developed rating ^a	0	50	50	50	115
Water vapor permeability ^b , ng/(s·m·Pa)	0.007	0.15	3.0	6.5	2.2
Thermal conductivity ^c , W/(m·K)					
At –20°C mean temperature	0.039	0.036	—	0.027	—
At +25°C mean temperature	0.045	0.039	0.019	0.027	0.035
At +50°C mean temperature	0.048	0.042	0.022	0.030	0.037

^aTested in accordance with ASTM E84 for 25 mm thick insulation.

^bTested in accordance with ASTM E96, Procedure A. Cellular glass tested with ASTM E96, Procedure B.

^cTested at 180 days of age in accordance with ASTM C177 or C518.

Cellular glass, closed-cell phenolic, flexible elastomeric, polyisocyanurate, and polystyrene are insulation materials commonly used in refrigerant applications. Designers should specify compliance with the material properties for each insulation in [Table 2](#). [Table 2](#) lists physical properties and [Tables 3](#) through [12](#) list recommended thicknesses for pipe insulation based on condensation control or for limiting heat gain.

- **Cellular glass** has excellent compressive strength, but it is rigid. Density varies between 100 and 140 kg/m³. Density does not greatly affect the thermal performance of cellular glass. It is fabricated to be used on piping and vessels. When installed on applications that are subject to excessive vibration, the inner surface of the material may need to be coated. The coefficient of thermal expansion for this material is relatively close to that of carbon steel. When installed on refrigeration systems, provisions for expansion and contraction of the insulation are usually only recommended for applications that cycle from below-ambient to high temperatures.
- **Flexible elastomerics** are soft and flexible. This material is suitable for use on nonrigid tubing, and its density ranges from 48 to 136 kg/m³. It has a low vapor permeability and normally requires no supplemental vapor retarder protection.
- **Closed-cell phenolic foam insulation** has a very low thermal conductivity, and is able to provide the same thermal performance as other insulations at a reduced thickness. It has a density of 16 to 48 kg/m³.
- **Polyisocyanurate insulation** has a low thermal conductivity and excellent compressive strength. Density ranges from 29 to 96 kg/m³.
- **Polystyrene insulation** has good compressive strength. Typical density range is 24 to 40 kg/m³.

Insulation Joint Sealant/Adhesive

All insulation materials that operate in below-ambient conditions should be protected by a continuous vapor retarder system. Joint sealants contribute to the effectiveness of this system. The sealant should resist liquid water and water vapor, and should bond to the specific insulation surface. The sealant should be applied at all seams, joints, terminations, and penetrations to retard the transfer of water and water vapor into the system.

Vapor Retarders

The insulation materials should be protected by a continuous and effective vapor retarder. The vapor retarder performance of the insulation system may be either integral to the insulation or from a vapor retarder material applied to the exterior surface of the insulation.

The service life of the insulation and pipe depends primarily on the installed water vapor permeance of the system, comprised of the permeance of the insulation, vapor retarders on the insulation, and

the sealing of all joints, seams, and penetrations. Therefore, the vapor retarder must be free of discontinuities and penetrations. It must be installed so that expansion and contraction can occur without compromising the integrity of the vapor retarder. The manufacturer should have specific design and installation instructions for their products.

Vapor retarders may be of the following types:

- **Metallic foil or all service jacket (ASJ) retarders** are applied to the surface of the insulation by the manufacturer or field applied. This type of jacket has a low water vapor permeance under ideal conditions [1.15 ng/(s·m²·Pa)]. These jackets have longitudinal joints and butt joints, so achieving low permeability depends on complete sealing of all joints and seams as. The jackets may be sealed with a contact adhesive applied to both overlapping surfaces. Manufacturers' instructions must be strictly followed during the installation. Butt joints are sealed in a similar fashion using metallic-faced ASJ material and contact adhesive. ASJ jacketing, when used outdoors with metal jacketing, may be damaged by the metal jacketing, so extra care should be taken when installing it. Pressure-sensitive adhesive systems for lap joints and butt joints may be acceptable, but they must be properly sealed.
- **Coatings, mastics, and heavy, paint-type products** applied by trowel, brush, or spraying, are available for covering insulation. The permeability of the materials is a function of the thickness applied. Some products are recommended for indoor use only, whereas others are available for indoor or outdoor use. These products may impart odors and manufacturers' instructions should be meticulously followed. Care should also be taken to insure that the mastics used are chemically compatible with the insulation system.

Mastics should be applied in two coats (with an open-weave fiber reinforcing mesh) to obtain a total dry-film thickness as recommended by the manufacturer. The mastic should be applied as a continuous monolithic retarder and extend at least 50 mm over any membrane where applicable. This is typically done only at valves and fittings. Mastics must be tied to the rest of the insulation or bare pipe at the termination of the insulation, preferably with a 50 mm overlap to maintain continuity of the retarder.

- A **laminated membrane retarder**, consisting of a rubber bitumen layer adhered to a plastic film, is also an acceptable and commonly used vapor retarder. This type of retarder has a very low permeance of 0.86 ng/(s·m²·Pa). Some solvent-based adhesives can attack this vapor retarder. All joints should have a 50 mm overlap to ensure adequate sealing. Other types of finishes may be appropriate depending on environmental or other factors.
- **Homogeneous polyvinylidene chloride films** are another type of commonly and successfully used vapor retarder. This type of vapor retarder is available in thicknesses ranging from 50 to 150 µm. Its permeance is very low, is dependent on thickness, and

Table 3 Cellular Glass Insulation Thickness for Indoor Design Conditions
(32°C Ambient Temperature, 80% Relative Humidity, 0.9 Emittance, 0 km/h Wind Velocity)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+5	−7	−20	−30	−40	−50	−60	−70
15	25	25	40	40	50	50	50	65
20	25	40	40	50	50	50	65	65
25	25	40	40	50	50	50	65	65
40	25	40	40	50	65	65	75	75
50	25	40	40	50	65	65	75	75
65	25	40	50	65	65	75	75	75
75	25	40	50	65	65	75	75	75
100	25	40	50	65	65	75	75	90
125	40	40	50	65	65	75	75	90
150	40	50	50	65	75	75	90	90
200	40	50	50	65	75	75	90	90
250	40	50	50	65	75	90	90	100
300	40	50	50	65	75	90	90	100
350	40	50	65	75	75	90	100	100
400	40	50	65	75	90	90	100	115
450	40	50	65	75	90	90	100	115
500	40	50	65	75	90	90	100	115
600	40	50	65	75	90	100	100	115
700	40	50	65	75	90	100	100	115
750	40	50	65	75	90	100	100	115
900	40	50	65	75	90	100	115	115

Notes:

1. Insulation thickness is chosen to either prevent or minimize condensation on the outside pipe surface or to limit heat gain to 25 W/m², whichever thickness is greater.

2. All thicknesses are in millimetres.

3. These values do not include a safety factor or aging factor. Actual operating conditions may vary. Consult a design engineer for an appropriate recommendation for your specific system.

4. Data calculated using NAIMA 3E Plus program.

Table 4 Cellular Glass Insulation Thickness for Outdoor Design Conditions
(38°C Ambient Temperature, 90% Relative Humidity, 0.4 Emittance, 12 km/h Wind Velocity)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+5	−7	−20	−30	−40	−50	−60	−70
15	40	50	65	75	90	90	100	100
20	50	65	75	90	90	90	90	100
25	50	65	65	75	90	100	100	115
40	65	75	75	90	100	115	115	125
50	50	65	75	90	100	115	115	125
65	65	75	90	100	115	125	125	140
75	65	75	90	100	115	125	125	140
100	65	75	90	100	115	125	140	150
125	65	90	100	115	125	140	150	165
150	65	90	100	115	125	140	150	165
200	75	90	115	125	140	150	165	180
250	75	100	115	140	150	180	180	190
300	75	100	115	140	150	180	190	205
350	90	100	125	140	165	180	190	205
400	90	115	125	150	165	180	190	215
450	90	115	125	150	165	190	205	215
500	90	115	125	150	180	190	205	215
600	90	115	125	150	180	190	205	230
700	90	115	140	165	180	205	215	230
750	90	115	140	165	180	205	215	230
900	90	115	140	165	190	205	230	240

Notes:

1. Insulation thickness is chosen to either prevent or minimize condensation on the outside pipe surface or to limit heat gain to 25 W/m², whichever thickness is greater.

2. All thicknesses are in millimetres.

3. These values do not include a safety factor or aging factor. Actual operating conditions may vary. Consult a design engineer for an appropriate recommendation for your specific system.

4. Data calculated using NAIMA 3E Plus program.

Table 5 Flexible Elastomeric Insulation Thickness for Indoor Design Conditions

(32°C Ambient Temperature, 80% Relative Humidity, 0.9 Emittance, 0 km/h Wind Velocity)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+5	−7	−20	−30	−40	−50	−60	−70
15	25	25	40	40	50	50	50	50
20	25	25	40	50	50	50	65	65
25	25	25	40	50	50	50	65	65
40	25	25	40	50	50	65	65	75
50	25	25	50	50	50	65	75	75
65	25	40	50	50	65	65	75	75
75	25	40	50	50	65	65	75	75
100	25	40	50	65	65	75	75	75
125	40	40	50	65	65	75	90	90
150	40	50	50	65	75	75	90	90
200	40	50	50	65	75	75	90	90
250	40	50	50	65	75	90	90	90
300	40	50	50	65	75	90	100	100
350	40	50	65	65	75	90	100	100
400	40	50	65	65	90	90	100	100
450	40	50	65	65	90	90	100	115
500	40	50	65	75	90	90	100	115
600	40	50	65	75	90	100	100	115
700	40	50	65	75	90	100	100	115
750	40	50	65	75	90	100	100	115
900	40	50	65	75	90	100	115	115

Notes:

1. Insulation thickness is chosen to either prevent or minimize condensation on the outside pipe surface or to limit heat gain to 25 W/m², whichever thickness is greater.

2. All thicknesses are in millimetres.

3. These values do not include a safety factor or aging factor. Actual operating conditions may vary. Consult a design engineer for an appropriate recommendation for your specific system.

4. Data calculated using NAIMA 3E Plus program.

Table 6 Flexible Elastomeric Insulation Thickness for Outdoor Design Conditions

(38°C Ambient Temperature, 90% Relative Humidity, 0.4 Emittance, 12 km/h Wind Velocity.)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+5	−7	−20	−30	−40	−50	−60	−70
15	40	50	65	65	65	75	75	75
20	50	65	65	65	75	75	90	90
25	50	65	65	75	75	90	90	100
40	50	65	75	75	75	90	100	100
50	50	75	75	75	90	100	100	115
65	65	75	75	75	90	100	100	115
75	65	75	90	90	100	115	115	125
100	65	75	90	100	115	115	125	125
125	65	90	100	100	115	125	125	140
150	65	90	100	115	115	125	140	150
200	75	90	115	115	125	140	150	165
250	75	100	115	125	140	150	165	180
300	75	100	115	140	140	150	165	180
350	90	100	125	140	150	165	165	180
400	90	115	125	140	150	165	180	190
450	90	115	125	140	150	165	180	190
500	90	115	125	140	150	165	180	190
600	90	115	125	140	165	180	190	205
700	90	115	140	150	165	180	190	205
750	90	115	140	150	165	180	190	205
900	90	115	140	150	180	180	190	205

Notes:

1. Insulation thickness is chosen to either prevent or minimize condensation on the outside pipe surface or to limit heat gain to 25 W/m², whichever thickness is greater.

2. All thicknesses are in millimetres.

3. These values do not include a safety factor or aging factor. Actual operating conditions may vary. Consult a design engineer for an appropriate recommendation for your specific system.

4. Data calculated using NAIMA 3E Plus program.

Table 7 Closed-Cell Phenolic Foam Insulation Thickness for Indoor Design Conditions
(32°C Ambient Temperature, 80% Relative Humidity, 0.9 Emittance, 0 km/h Wind Velocity)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+5	−7	−20	−30	−40	−50	−60	−70
15	25	25	25	25	40	40	40	40
20	25	25	25	40	40	40	40	40
25	25	25	25	40	40	40	40	40
40	25	25	25	40	40	40	40	40
50	25	25	25	40	40	40	40	40
65	25	25	25	40	40	40	40	40
75	25	25	25	40	40	50	50	50
100	25	25	40	40	40	50	50	50
125	25	25	40	40	40	50	50	65
150	25	25	40	40	50	50	50	65
200	25	25	40	40	50	50	50	65
250	25	25	40	40	50	50	50	65
300	25	25	40	40	50	50	50	65
350	25	25	40	40	50	50	50	65
400	25	25	40	40	50	50	65	65
450	25	25	40	40	50	50	65	65
500	25	25	40	40	50	50	65	65
600	25	25	40	40	50	50	65	65
700	25	25	40	40	50	50	65	65
750	25	25	40	40	50	50	65	65
900	25	25	40	50	50	50	65	65

Notes:

1. Insulation thickness is chosen to either prevent or minimize condensation on the outside pipe surface or to limit heat gain to 25 W/m², whichever thickness is greater.

2. All thicknesses are in millimetres.

3. These values do not include a safety factor or aging factor. Actual operating conditions may vary. Consult a design engineer for an appropriate recommendation for your specific system.

4. Data calculated using NAIMA 3E Plus program.

Table 8 Closed-Cell Phenolic Foam Insulation Thickness for Outdoor Design Conditions
(38°C Ambient Temperature, 90% Relative Humidity, 0.4 Emittance, 12 km/h Wind Velocity)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+5	−7	−20	−30	−40	−50	−60	−70
15	25	25	40	40	40	50	50	50
20	25	40	40	40	50	50	50	65
25	25	40	40	40	50	50	50	65
40	25	40	40	40	50	50	50	65
50	25	40	40	40	50	50	65	65
65	25	40	40	40	50	50	65	65
75	25	40	50	50	65	65	75	75
100	40	40	50	65	65	75	75	75
125	40	50	50	65	65	75	75	90
150	40	50	50	65	75	75	90	90
200	40	50	65	65	75	75	90	100
250	40	50	65	65	75	90	90	100
300	40	50	65	75	75	90	100	100
350	40	50	65	75	90	90	100	115
400	40	50	65	75	90	100	100	115
450	40	65	65	75	90	100	100	115
500	50	65	65	75	90	100	100	115
600	50	65	75	75	90	100	115	125
700	50	65	75	75	90	100	115	125
750	50	65	75	90	90	100	115	125
900	50	65	75	90	90	100	115	125

Notes:

1. Insulation thickness is chosen to either prevent or minimize condensation on the outside pipe surface or to limit heat gain to 25 W/m², whichever thickness is greater.

2. All thicknesses are in millimetres.

3. These values do not include a safety factor or aging factor. Actual operating conditions may vary. Consult a design engineer for an appropriate recommendation for your specific system.

4. Data calculated using NAIMA 3E Plus program.

Table 9 Polyisocyanurate Foam Insulation Thickness for Indoor Design Conditions

(32°C Ambient Temperature, 80% Relative Humidity, 0.9 Emittance, 0 km/h Wind Velocity)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+5	−7	−20	−30	−40	−50	−60	−70
15	25	25	40	40	40	40	50	50
20	25	25	40	40	40	50	50	50
25	25	25	40	40	40	50	50	50
40	25	25	40	40	40	50	50	50
50	25	25	40	40	40	50	50	65
65	25	25	40	40	40	50	50	65
75	25	25	40	40	50	65	65	65
100	25	25	40	40	50	65	65	75
125	25	40	40	50	50	65	65	75
150	25	40	40	50	50	65	65	75
200	25	40	40	50	50	65	65	75
250	25	40	40	50	50	75	75	90
300	25	40	40	50	65	75	75	90
350	25	40	40	50	65	75	75	90
400	25	40	50	50	65	75	75	90
450	25	40	50	50	65	75	90	90
500	25	40	50	50	65	75	90	90
600	25	40	50	50	65	75	90	90
700	25	40	50	50	65	75	90	100
750	25	40	50	50	65	75	90	100
900	25	40	50	50	65	75	90	100

Notes:

1. Insulation thickness is chosen to either prevent or minimize condensation on the outside pipe surface or to limit heat gain to 25 W/m², whichever thickness is greater.

2. All thicknesses are in millimetres.

3. These values do not include a safety factor or aging factor. Actual operating conditions may vary. Consult a design engineer for an appropriate recommendation for your specific system.

4. Data calculated using NAIMA 3E Plus program.

Table 10 Polyisocyanurate Foam Insulation Thickness for Outdoor Design Conditions

(38°C Ambient Temperature, 90% Relative Humidity, 0.4 Emittance, 12 km/h Wind Velocity)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+5	−7	−20	−30	−40	−50	−60	−70
15	25	40	40	50	50	65	65	65
20	25	40	50	50	65	65	65	75
25	25	40	50	50	65	65	75	90
40	40	40	50	50	65	65	75	90
50	40	40	50	65	75	75	90	100
65	40	40	50	65	75	75	90	100
75	40	50	65	75	75	90	100	115
100	40	50	65	75	90	90	100	115
125	40	50	65	75	90	100	115	125
150	50	65	75	75	90	100	115	125
200	50	65	75	90	100	115	125	140
250	50	65	75	90	100	115	125	150
300	50	65	75	90	115	125	140	150
350	50	65	90	100	115	125	140	150
400	50	75	90	100	115	125	150	165
450	50	75	90	100	115	140	150	165
500	50	75	90	100	115	140	150	165
600	50	75	90	100	125	140	150	180
700	50	75	90	100	125	140	150	180
750	65	75	90	100	125	140	165	180
900	65	75	90	100	125	140	165	180

Notes:

1. Insulation thickness is chosen to either prevent or minimize condensation on the outside pipe surface or to limit heat gain to 25 W/m², whichever thickness is greater.

2. All thicknesses are in millimetres.

3. These values do not include a safety factor or aging factor. Actual operating conditions may vary. Consult a design engineer for an appropriate recommendation for your specific system.

4. Data calculated using NAIMA 3E Plus program.

Table 11 Polystyrene Foam Insulation Thickness for Indoor Design Conditions
(32°C Ambient Temperature, 80% Relative Humidity, 0.9 Emittance, 0 km/h Wind Velocity)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+5	−7	−20	−30	−40	−50	−60	−70
15	25	40	40	50	50	50	65	65
20	40	40	40	50	50	65	65	65
25	40	40	40	50	50	65	65	65
40	40	40	50	50	50	65	65	65
50	40	40	50	50	65	65	65	75
65	40	40	50	50	65	65	65	75
75	40	50	50	65	65	75	75	90
100	40	50	50	65	75	75	75	90
125	40	50	65	65	75	75	90	90
150	40	50	65	65	75	90	90	90
200	40	50	65	65	75	90	90	100
250	40	50	65	75	75	90	100	100
300	40	50	65	75	90	90	100	100
350	40	50	65	75	90	100	100	100
400	40	50	65	75	90	100	100	115
450	40	50	65	75	90	100	100	115
500	40	65	75	75	90	100	100	115
600	40	65	75	90	90	100	100	115
700	40	65	75	90	90	100	115	115
750	40	65	75	90	90	100	115	115
900	50	65	75	90	100	100	115	125

Notes:

1. Insulation thickness is chosen to either prevent or minimize condensation on the outside pipe surface or to limit heat gain to 25 W/m², whichever thickness is greater.

2. All thicknesses are in millimetres.

3. These values do not include a safety factor or aging factor. Actual operating conditions may vary. Consult a design engineer for an appropriate recommendation for your specific system.

4. Data calculated using NAIMA 3E Plus program.

Table 12 Polystyrene Foam Insulation Thickness for Outdoor Design Conditions
(38°C Ambient Temperature, 90% Relative Humidity, 0.4 Emittance, 12 km/h Wind Velocity)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+5	−7	−20	−30	−40	−50	−60	−70
15	40	50	65	65	65	75	75	75
20	40	50	65	65	75	75	90	90
25	40	50	65	75	75	90	90	100
40	50	50	65	75	75	90	100	100
50	50	65	75	75	90	100	100	115
65	50	65	75	75	90	100	100	115
75	65	75	90	90	100	115	115	125
100	65	75	90	100	115	115	125	125
125	65	75	90	100	115	125	125	140
150	65	90	90	115	115	125	140	150
200	65	75	115	115	125	140	150	165
250	75	90	115	125	140	150	165	180
300	75	90	115	125	140	150	165	180
350	75	100	115	140	150	165	165	180
400	75	100	125	140	150	165	180	190
450	90	100	125	140	150	165	180	190
500	90	100	125	140	150	165	180	190
600	90	100	125	140	165	180	190	205
700	90	100	125	150	165	180	190	205
750	90	100	125	150	165	180	190	205
900	90	115	125	150	165	180	190	205

Notes:

1. Insulation thickness is chosen to either prevent or minimize condensation on the outside pipe surface or to limit heat gain to 25 W/m², whichever thickness is greater.

2. All thicknesses are in millimetres.

3. These values do not include a safety factor or aging factor. Actual operating conditions may vary. Consult a design engineer for an appropriate recommendation for your specific system.

4. Data calculated using NAIMA 3E Plus program.

ranges from 0.58 to 1.15 ng/(s·m·Pa). Some solvent-based adhesives can attack this vapor retarder. All joints should have a 25 to 50 mm overlap to ensure adequate sealing and can be sealed with tapes made from the same film or various adhesives.

Weather Barrier/Jacketing

Weather barrier jacketing on insulated pipes and vessels protects the vapor retarder system and insulation. Various plastic and metallic products are available for this purpose. Some specifications suggest that the jacketing should function to preserve and protect the sometimes fragile vapor retarder over the insulation. This being the case, bands must be used to secure the jacket. Pop rivets, sheet metal screws, staples, or any other items that puncture should not be used because they will compromise the vapor retarder system. The use of such materials may indicate that the installer does not understand the vapor retarder concept and corrective education steps should be taken.

Protective jacketing is designed to be installed over the vapor retarder and insulation to prevent weather and abrasion damage. The protective jacketing must be installed independently and in addition to any factory- or field-applied vapor retarder. Ambient-temperature cycling will cause the jacketing to expand and contract. The manufacturer's instructions should show how to install the jacketing to permit this expansion and contraction.

Metal jacketing may be smooth, textured, embossed, or corrugated aluminum or stainless steel with a continuous moisture retarder. Metallic jackets are recommended for exposed, roof-mounted piping.

Protective jacketing is required whenever piping is exposed to washing, physical abuse, or traffic. White PVC (0.75 mm thick) is popular inside buildings where degradation from sunlight is not a factor. Colors can be obtained at little, if any, additional cost. All longitudinal and circumferential laps should be seal welded using a solvent welding adhesive. The laps should be located at the ten o'clock or two o'clock positions. A sliding lap (PVC) expansion/contraction joint should be located near each endpoint and at immediate joints no more than 6 m apart. Where very heavy abuse and/or hot, scalding washdowns are encountered, a CPVC material is required. These materials can withstand temperatures as high as 110°C, whereas standard PVC will warp and disfigure at 60°C.

Roof piping should be jacketed with a minimum 0.41 mm aluminum (embossed or smooth finish depending on aesthetic choice). On pitched lines, this jacketing should be installed with a minimum 50 mm overlap arranged to shed any water in the direction of the pitch. Only stainless steel bands should be used to install this jacketing (13 mm wide by 0.50 mm thick 304 stainless) and spaced every 300 mm. Jacketing on valves and fittings should match that of the adjacent piping.

INSTALLATION GUIDELINES

Preliminary Preparation. Corrosion of any metal under any thermal insulation can occur for many reasons. With any insulation, the pipe can be primed to minimize the potential for corrosion. The following should be completed before installing the insulation:

- Complete all welding and other hot work
- Complete hydrostatic and other performance testing
- Remove oil, grease, loose scale, rust, and foreign matter from surfaces to be insulated. Surface must also be dry and free from frost.
- Complete site touch-up of all shop coating, including preparation and painting at field welds. (*Note:* Do not use varnish on welds of ammonia systems.)

Insulating Fittings and Joints. Insulation for fittings, flanges, and valves should be the same thickness as the insulation of the pipe and must be fully vapor sealed. The following guidelines also are applicable:

- If the valve design allows, valves should be insulated to the packing glands.
- Stiffener rings, where provided on vacuum equipment and/or piping, should be insulated with the same thickness and type of insulation as specified for that piece of equipment or line. The rings should be fully independently insulated.
- Where multiple layers of insulation are used, all joints should be staggered or beveled where appropriate.
- Insulation should be applied with all joints fitted to eliminate voids. Large voids should not be filled with vapor sealant or fibrous insulation, but eliminated by refitting or replacing the insulation.
- All joints, with the exception of contraction joints and the inner layer of a double layer system, should be sealed with either the proper adhesive or a joint sealer during installation.
- Each line should be insulated as a single unit. Adjacent lines must not be enclosed within a common insulation cover.

Planning Work. Insulations require special protection during storage and installation to avoid physical abuse and to keep them clean and dry. All insulation applied in one day should also have the vapor barrier installed. When specified, at least one coat of vapor retarder mastic should be applied the same day. If impractical to apply the first coat of vapor retarder mastic, the insulation must be temporarily protected with a moisture retarder, such as an appropriate polyethylene film, and sealed to the pipe or equipment surface. All exposed insulation terminations should be protected before work ends for the day.

Vapor Stops. Vapor stops should be installed using either sealant or the appropriate adhesive at all directly attached pipe supports, guides, anchors, and at all locations requiring potential maintenance, such as valves, flanges, and instrumentation connections to piping or equipment. If valves or flanges must be left uninsulated until after plant start-up, temporary vapor stops should be installed using either sealant or the appropriate adhesive at approximately every 3 m on straight runs.

Securing Insulation. When applicable, the innermost layer of insulation should be applied in two half-sections and secured with 19 mm wide pressure-sensitive filament tape banding spaced a maximum of 230 mm apart and applied with a 50% overlap. Single and outer layers more than 450 mm in diameter and inner layers with radiused and beveled segments should be secured by 9.5 mm wide stainless steel bands spaced on 230 mm maximum centers. The bands must be firmly tensioned and sealed.

Applying Vapor Retarder Coating and Mastic. *First coat:* Irregular surfaces and fittings should be vapor sealed by applying a thin coat of vapor retarder mastic or finish with a minimum wet-film thickness as recommended by the manufacturer. While the mastic or finish is still tacky, an open-weave glass fiber reinforcing mesh should be laid smoothly into the mastic or finish and should be thoroughly embedded in the coating. Care should be taken not to rupture the weave. The fabric should be overlapped a minimum of 50 mm at joints to provide strength equal to that maintained elsewhere.

Second coat: Before the first coat is completely dry, a second coat should be applied over the glass fiber reinforcing mesh with a smooth, unbroken surface. The total thickness of the mastic or finish should be in accordance with the coating manufacturer's recommendation.

Pipe Supports and Hangers. When possible, the pipe hanger or support should be located outside of the insulation. Supporting the pipe outside of the protective jacketing eliminates the need to insulate over the pipe clamp, hanger rods, or other attached support components. This method minimizes the potential for vapor intrusion and thermal bridges because a continuous envelope surrounds the pipe.

ASME *Standard* B31 establishes basic stress allowances for piping material. The loading on the insulation material is a func-

Table 13 Suggested Pipe Support Spacing for Straight Horizontal Runs

Nominal Pipe OD, mm	Standard Steel Pipe ^{a, b}	Copper Tube
	Support Spacing, m	
15	1.8	1.5
20	1.8	1.5
25	1.8	1.8
40	3.0	2.4
50	3.0	2.4
65	3.3	2.7
75	3.6	3.0
100	4.2	3.6
150	4.9	—
200	4.9	—
250	4.9	—
300	4.9	—
350	4.9	—
400	4.9	—
450	4.9	—
500	4.9	—
600	4.9	—

Source: Adapted from MSS Standard SP-69 and ASME B31.1

^aSpacing does not apply where span calculations are made or where concentrated loads are placed between supports such as flanges, valves, specialties, etc.

^bSuggested maximum spacing between pipe supports for horizontal straight runs of standard and heavier pipe.

tion of its compressive strength. [Table 13](#) suggests spacing for pipe supports. Related information in this table is also in [Chapter 41 of the ASHRAE Handbook—HVAC Systems and Equipment](#).

The insulation material may or may not have the compressive strength to support loading at these distances. Therefore, the force due to the load of the piping and contents on the bearing area of the insulation should be calculated. In refrigerant piping, bands or clevis hangers typically are used with rolled metal shields or cradles between the band or hanger and the insulation. Although the shields are typically rolled to wrap the outer diameter of the insulation in an arc of 180°, the bearing area is calculated over a 120° arc of the outer circumference of the insulation multiplied by the shield length. If the insulated pipe is subjected to point loading such as where it rests on a beam or a roller, the bearing area arc is reduced to 60° and multiplied by the shield length. In this case, rolled plate may be more suitable than sheet metal. Provisions should be made to secure the shield on both sides of the hanger (metal band), and the shield should be centered in the support. [Table 14](#) lists widths and thicknesses for pipe shields.

Expansion Joints. Some installations require an expansion or contraction joint. These joints are normally required in the innermost layer of insulation, and may be constructed in the following manner:

1. Make a 25 mm break in the insulation.
2. Tightly pack the break with fibrous insulation material.
3. Secure insulation on either side of the joint with stainless steel bands that have been hand-tightened.
4. Cover the joint with an appropriate vapor retarder and seal properly.

The presence and spacing of expansion/contraction joints is an important design issue in insulation systems used on refrigerant piping. Spacing may be calculated using the following equation:

Table 14 Shield Dimensions for Insulated Pipe and Tubing

Insulation Diameter, mm	Shield Thickness, gage (mm)	Shield Arc Length, mm	Shield Length, mm	Shield Radius, mm
65	20 (0.91)	65	300	35
75	20 (0.91)	80	300	40
90	18 (1.22)	90	300	45
100	18 (1.22)	105	300	50
115	18 (1.22)	130	300	60
125	16 (1.52)	140	300	65
150	16 (1.52)	165	300	80
200	16 (1.52)	215	450	105
250	14 (1.91)	265	450	130
300	14 (1.91)	315	450	155
350	14 (1.91)	370	450	180
400	12 (2.67)	485	450	230
500	12 (2.67)	535	450	255
550	12 (2.67)	585	450	280
600	12 (2.67)	635	450	305
650	12 (2.67)	685	450	330
700	12 (2.67)	750	450	355
750	12 (2.67)	800	450	385

Source: Adapted from IAR Ammonia Refrigeration Handbook.

Note: Protection shield gages listed are for use with band-type hangers only. For point loading, increase shield thickness and length.

Table 15 COLTE Values for Various Materials

Material	COLTE ^a , mm/(m·K)
Pipe	
Carbon steel	0.0102
Stainless steel	0.0157
Aluminum	0.0202
Ductile iron	0.0092
Copper ^b	0.0169
Insulation	
Cellular glass	0.0060
Flexible elastomeric	N/A
Closed-cell phenolic	0.0510
Polyisocyanurate	0.0900
Polystyrene	0.0630

^aMean COLTE between 21 and -70°C from Perry's Chemical Engineer's Handbook, Seventh ed., Table 10-52.

^bCOLTE between 20 and 100°C from Perry's Chemical Engineer's Handbook, Seventh ed., Table 28-4.

$$S = \frac{L}{\left[\left(|T_i - T_o| \times |\alpha_i - \alpha_p| \times \frac{L}{d} \right) + 1 \right]}$$

where

S = worst case maximum spacing of contraction joints, m

T_i = temperature during installation of insulation, °C

T_o = coldest service temperature of the pipe, °C

α_i = Coefficient of Linear Thermal Expansion (COLTE) of the insulation material, mm/(m·K)

α_p = COLTE of the pipe material, mm/(m·K)

L = length of the pipe, m

d = amount of expansion or contraction that can be absorbed by each insulation contraction joint, mm

[Table 15](#) provides the COLTEs for various pipe and insulation materials. The values in these tables can be used in the previous equation as α_i and α_p .

MAINTENANCE OF INSULATION SYSTEMS

Periodic inspections of refrigerant piping systems are needed to determine the presence of moisture, which will degrade an insulation system's thermal efficiency and shorten its service life. The frequency of inspection should be determined by the critical nature of the process, the external environment, and the age of the insulation. A *routine* inspection should include the following checks:

- Look for signs of moisture or ice on the lower part of horizontal pipe, at the bottom elbow of a vertical pipe, and around pipe hangers and saddles (moisture may migrate to low areas).
- Look for mechanical damage and jacketing penetrations, openings, or separations.
- Check the jacketing to determine if the banding is loose.
- Look for bead caulking failure, especially around flange and valve covers.
- Look for loss of jacketing integrity and for open seams around all intersecting points, such as pipe transitions, branches, and tees.
- Look for cloth visible through the mastic or finish if the pipe is protected by a reinforced mastic weather barrier.

An *extensive* inspection of an insulation system should also include the following:

- Use thermographic equipment to isolate areas of concern.
- Design a method to repair, close, and seal any cut in the insulation or vapor retarder so that a positive seal may be maintained throughout the entire system.
- Examine the pipe surface for corrosion if the insulation is wet.

The extent of moisture present in the insulation system and/or the corrosion of the pipe will determine the need to replace the insulation. All wet parts of the insulation must be replaced.

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