CHAPTER 10

INSULATION SYSTEMS FOR REFRIGERANT PIPING

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. See Chapters 23, 25, 26, and 27 in the 2021 *ASHRAE Handbook—Fundamentals* for information about insulation and vapor retarders (barriers) for these systems.

The success of an insulation system for cold piping, such as refrigerant piping, depends on factors such as

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

Refrigerant piping includes lines that run at cold temperature, that cycle between hot and cold, and even some that run at temperatures above ambient. These pipes use various insulation materials and systems, and are insulated for the following reasons:

- Energy conservation
- Economics (to minimize 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

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 its thickness (see Tables 3 to 12) based on specific design conditions. All fabricated pipe, valve, and fitting insulation should have dimensions and tolerances in accordance with ASTM *Standards* C450 and C585. All materials used for thermal insulation should be installed in accordance with project specifications. For guidance in writing project specifications, consult the Midwest Insulation Contractors Association's (MICA) National Commercial and Industrial Insulation Standards and manufacturers' recommendations.

This preparation of this chapter is assigned to TC 10.3, Refrigerant Piping, Controls and Accessories.

1. 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. Other reasons include noise reduction and personnel protection. For most outdoor installations, the thickness required to prevent surface condensation controls the design. With appropriate design conditions and insulation properties, computer programs using the ASTM *Standard* C680 calculation methodology may be helpful in calculating the required insulation thickness. Tables 3 to 12 give insulation thickness recommendations for several design conditions for various insulation materials. Note that these tables apply only to the conditions specified, and that the outdoor design conditions are a particularly harsh scenario. If any of these conditions are different for a specific project, then these tables are likely to no longer be accurate. Most insulation manufacturers can provide insulation thickness tables for the conditions of a specific project. The most economical insulation thickness can be determined by considering both initial costs and long-term energy savings. In practice, this requires the designer to determine or assume values for a wide variety of variables that usually are not known with any degree of certainty. For insulation applied to cold pipe, it is more common to specify the insulation thickness that delivers a heat gain into the insulation system of 25 W/m^2 of outer jacket surface. This popular rule of thumb was used to generate Tables 3 to 12, because the variability of energy costs and fluctuations of the myriad of economic parameters needed to do a thorough economic analysis go beyond the scope of this chapter.

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, effective, and low-permeance vapor retarder system to limit the amount of water vapor entering the insulation system.

Various insulation and accessory materials are used in systems for refrigerant piping. Successful system designs specify the best solution for material selection, vapor retarder system (including closures), installation procedures, operations, and maintenance to achieve long-term satisfactory performance, meeting all criteria imposed by the owner, designer, engineer, and code officials.

2. 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, thermal conductivity values are determined (under laboratory conditions) by ASTM *Standard* C335-13. However, this method is generally run only at above-ambient conditions, making it of little use for other applications. In most cases, for below-ambient conditions, thermal conductivity values are determined on flat specimens under laboratory conditions using ASTM *Standard* C177-13 or C518-17. Determining the effective thermal conductivity requires analysis using the conductivity versus temperature relationship from ASTM *Standard* C1045 and the specific hot and cold surface temperatures. 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 unit area 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 the resistance of the material or system to passing water vapor. The unit of water vapor permeance is ng/(Pa·s·m^2), and data are determined by ASTM *Standard* E96-16. As with thermal conductivity, permeance can vary with conditions. Data for most insulation materials are determined using ASTM *Standard* E96-16 at room temperature using the desiccant method (procedure A: 0 and 50% rh on opposite sides of the specimen) or water method (procedure B: 50% and 100% rh on opposite sides of the specimen). Water vapor permeance can be critical in design because water vapor can penetrate materials or systems that are unaffected by liquid water. Water vapor diffusion is a particular concern to insulation systems subjected to a thermal gradient. Pressure differences between ambient conditions and the piping's colder operating conditions 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 physical damage to the insulation system and equipment. Thermal properties of 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 insulation and piping may open joints in the insulation, which not only creates 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 shrink and subsequently crack. At the high-temperature end of the cycle, the reverse is a concern: high thermal expansion coefficients may cause permanent warping or buckling in some insulation material, and this stress on an external vapor retarder or weather barrier should be considered. The possible negative consequences of expansion or contraction of insulation can be eliminated by proper system design, including use of appropriately designed and spaced expansion or contraction joints.

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

Wicking is the tendency of an insulation material to absorb liquid through 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.

3. INSULATION SYSTEM MOISTURE RESISTANCE

There are two approaches to providing a vapor retarder (barrier) for an insulation system for refrigerant piping:

- A low-permeance sheet, film, or mastic-type vapor retarder with a permeance of ≤1.14 ng/(Pa·s·m^2) on the outer surface of the insulation system
- An insulation material with a permeability/thickness combination that yields a permeance of ≤1.14 ng/(Pa·s·m^2), sealed at all of the circumferential and longitudinal joints with vapor retarder sealant

Historically, for low-permeance sheet, film, or mastic, discussions of and requirements for vapor retarder permeance have assumed flat, homogeneous pieces of the vapor retarder material with no joints present. The actual vapor retarder system performance, which is the critical issue, was not being tested. Although permeance testing of complete systems is still not possible, the permeance of sealed vapor retarder joints in a flat geometry can be examined using ASTM *Standard* C1809, which describes how vapor retarder joints are to be created for testing permeance using the common ASTM *Standard* E96 test method.

It is recommended that overlap and tape joints prepared using the *Standard* C1809 procedure also be required to have a permeance of ≤1.14 ng/(Pa·s·m^2), the same as the vapor retarder material.

For both approaches, seals at the joints and closures of the vapor retarder or insulation material are very important to overall vapor retarder system performance. It also is critical that the vapor retarder system be continuous and without holes, tears, cracks, etc., that would allow water vapor to enter the insulation system. Avoiding any flaws that would provide a path from the external environment to the pipe surface is of particular concern.

Refrigeration systems are often insulated to conserve energy and prevent surface condensation. An insulation system's resistance to water and water vapor intrusion is a critical consideration for many refrigerant piping installations. When the vapor retarder system fails, water vapor moves 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 condenses and freezes on or within the insulation. As more water vapor is absorbed, the insulation material's thermal conductivity increases, which leads to a lower surface temperature. This lower surface temperature leads to more condensation, which may cause physical damage to the insulation system and equipment as a result of ice formation. With refrigeration equipment operating at 2°C or lower, the problem may be severe.

If a continuous low-permeance vapor retarder system is properly installed with all joints and penetrations sealed and is not damaged in any way, then the insulation material's water resistance is not as important. In practice, however, it is very difficult to achieve and maintain perfect performance and continuity in a vapor retarder system. Therefore, the insulation material's water resistance is an important design consideration. An insulation material's water absorption and water vapor permeability properties are good indicators of its resistance to water. Because water intrusion 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, low permeability, and low wicking) should be used for refrigerant piping operating at temperatures below 2°C.

4. INSULATION SYSTEMS

The main elements of a below-ambient temperature insulation system include

- Pipe or surface preparation
- Insulation material
- Insulation joint sealant/adhesive
- Vapor stops (dams) with sealed annular space between pipe and pipe insulation
- Vapor retarders
- Tapes or sealants on vapor retarder joints
- 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 installing the insulation system. The pipe can be primed to minimize the potential for corrosion. Careful consideration during insulation system design is essential. The main 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.

Surfaces that operate continuously below –5°C (for insulated carbon steel) or 60°C (for stainless steel) 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, inadequate insulation system water vapor permeance, and improper installation of insulation.

Common flaws include the following:

- Incorrect insulation materials, joint sealants/adhesives, or vapor retarder system 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 installation 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 corrosion-promoting conditions include

- Annular space or crevice for water retention.
- Insulation material that may wick or absorb water.
- Insulation material that may contribute contaminants that can increase the corrosion rate. However, water entering the insulation systems (which is necessary for corrosion to occur) can bring with it a near-inexhaustible supply of corrosive contaminants from the ambient environment.

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 in the insulation itself. The breaks may result from 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 insulation surface temperature is lower than the dew point. Insulation systems cannot always be made completely vaportight, so water vapor pressure differences and condensation must be recognized in the system design.

The main contaminants that exacerbate corrosion are chlorides and sulfates, introduced during 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 the many protective coating systems that can be used for carbon steel. For other systems or for more details, contact the coating or pipe 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 and localized chemical reactions 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

- Oxygen (air).
- 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.
- A corrosive chemical.
- Water (or moisture), which allows copper corrosion 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 insulation and 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, such as applying stress to align a copper tube with a fitting or physically damaging the copper before installation.

Table 1 Protective Coating Systems for Carbon Steel Piping

Carbon Steel System Substrate No.	Temperature Range	Surface Profile	Prime Coat[a]	Intermediate Coat[a]	Finish Coat[a]
1	–45 to 60°C	50 to 75 µm	125 µm high-build (HB) epoxy	N/A	125 µm HB epoxy
2	–45 to 60°C	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
3	93°C maximum	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
	–45 to 150°C	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

Note: Surface preparation per NACE *Standard* 2/SSPC-SP-10. [a]Coating thicknesses are typical dry film values. [b]MIL-P-24441, Part 1. [c]MIL-P-24441, Part 2.

- Never use chlorinated solvents such as 1,1,1-trichloroethane to clean refrigeration equipment. These solvents have been linked to rapid corrosion.
- Use no acidic substances such as citric acid or acetic acid (vinegar) on copper. These 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 operating condition to avoid condensation on tubing.
- Never mechanically constrict (e.g., compress with wire ties) or adhere insulation to copper. This may result in water pooling between the insulation and 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 insulation or copper.
- Prevent water from entering between the insulation and the copper. Where system layout is such that condensation may form and run along uninsulated copper by gravity, completely adhere and seal the beginning run of insulation to the copper or install vapor stops.
- Use copper that complies with ASTM *Standard* B280-16. Buy copper from a reputable manufacturer.
- When pressure-testing copper tubing, take care not to exceed its specific yield point.
- 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 formation of stress cracks.
- Replace any insulation that has become wetted or saturated with refrigerant lubricating oils, which can react with moisture to form corrosive materials.

Stainless Steel. Some grades of stainless steel piping are susceptible to ESCC. ESCC occurs in austenitic stainless steel piping and equipment when corrosive ions in the environment or insulation material are transported in the presence of water to the hot stainless steel surface. Evaporation of the water can concentrate the corrosive ions, increasing the potential for ESCC. This situation occurs most commonly beneath thermal insulation, but the presence of insulation is not required: it simply provides a medium to hold and transport water, with its corrosive ions (e.g., soluble chlorides), to the metal surface.

Most ESCC failures occur when metal temperature is in the hot-water range of 60 to 150°C. Below 60°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 present at the low temperature evaporates at the higher temperature. During the high-temperature cycle, corrosive ions dissolved in the water concentrate on the surface.

It is important to note that the following insulation thickness tables apply only to the conditions specified and that the outdoor design conditions are a particularly harsh scenario. If any of these conditions are different for a specific project, then these tables are likely to no longer be accurate. If the jacket emittance is lower than is listed in the specified design conditions for a table, the required insulation thickness is likely to increase. Most insulation manufacturers can provide insulation thickness tables for the conditions of a specific project.

As with copper, sufficient tensile stress must be present in the stainless steel for ESCC to develop. 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. Consult a metallurgist 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 retarder systems and weather barriers must be installed over dry insulation. The insulation system (including all closure-type vapor retarders) should have a low thermal conductivity with low water vapor permeability.

Cellular glass, closed-cell phenolic, flexible elastomeric, polyisocyanurate, and extruded polystyrene insulation materials are 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 to 12 list recommended thicknesses for pipe insulation based on condensation control or for limiting heat gain.

Table 2 Properties of Insulation Materials[d,e]

	Cellular Glass	Flexible Elastomeric	Closed-Cell Phenolic	Polyisocyanurate	Extruded Polystyrene (XPS)
Specification containing material	ASTM C552-17, Type I, Grade 6	ASTM C534-16 Type I, Grade 1	ASTM C1126-15 Type III, Grade 1	ASTM C591-17 Type IV, Grade 2	ASTM C578-17a Type XIII
Suitable temp. range, °C	–270 to 430	–30 to 104	–179 to 125	–183 to 150	–183 to 75
Flame spread rating[a]	5	f	25	f	f
Smoke developed rating[a]	0	f	50	f	f
Water vapor permeability,[b] ng/(s·Pa·m)	0.007	0.15	7.2	5.8	2.2
Thermal conductivity,[c] W/(m·K)					
At –46°C mean temperature	0.034	0.035	0.028	0.027	0.029
At –20°C mean temperature	0.039	0.038	0.026	0.027	0.032
At +25°C mean temperature	0.045	0.040	0.026	0.027	0.037
At +50°C mean temperature	0.049	0.043	0.028	0.030	0.040

[a]Tested in accordance with ASTM *Standard* E84 using the specimen preparation and mounting techniques of *Standard* E2231.
[b]Tested in accordance with ASTM *Standard* E96, Procedure A. Cellular glass tested with ASTM *Standard* E96, Procedure B.
[c]Tested at 180 days of age (under laboratory conditions) in accordance with ASTM *Standard* C177 or C518. All thermal conductivity values as a function of mean temperatures are derived from testing flat insulation samples only.
[d]Most physical properties shown are taken from the applicable ASTM standards listed and represent requirements when tested at specific laboratory conditions. It is the design engineer's responsibility to ensure suitability of material under actual use conditions.
[e]Properties shown reflect performance requirements as listed in the specific year version of the referenced ASTM standard or other sources when this chapter was updated. Verify current performance requirements by consulting the most recent ASTM standard or manufacturer's data sheet.
[f]No requirements for this property are contained in the relevant ASTM material standard. Consult manufacturer for more information.

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

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+4	−7	−18	−29	−40	−51	−62	−73
15	25	40	40	50	50	65	65	65
20	40	40	50	50	65	65	65	75
25	25	40	50	50	65	65	75	75
40	40	40	50	50	65	65	75	75
50	40	50	50	65	65	75	90	90
65	40	40	50	65	65	75	75	90
75	40	50	65	65	75	90	90	100
100	40	50	65	75	75	90	90	100
125	40	50	65	75	75	90	100	100
150	40	50	65	75	90	90	100	100
200	40	50	65	75	90	100	100	115
250	40	50	65	75	90	100	115	115
300	40	50	65	75	90	100	115	125
350	50	65	75	90	100	115	115	125
400	50	65	75	90	100	115	115	125
450	50	65	75	90	100	115	125	125
500	50	65	75	90	100	115	125	140
600	50	65	75	90	100	115	125	140
700	50	65	75	90	100	115	125	140
750	50	65	75	90	100	115	125	140
900	50	65	75	90	100	115	125	140
Vert Flat	50	65	90	100	115	125	150	165
Tk Top	50	65	90	100	115	125	150	165
Tk Bot.	50	65	90	100	115	125	150	165

Notes:
1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 25 W/m², whichever thickness is greater, at the conditions specified.
2. Thicknesses shown are applicable only to the conditions specified. Changing any condition, even slightly, can influence the required thickness.
3. All thicknesses are in millimetres.
4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for the specific system.
5. Thickness calculated using ASTM *Standard* C680-14 methodology.

Table 4 Cellular Glass Insulation Thickness for Outdoor Design Conditions, mm
(38°C Ambient Temperature, 94% Relative Humidity, 0.1 Emittance, 12 km/h Wind Velocity)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+4	−7	−18	−29	−40	−51	−62	−73
15	40	40	50	65	65	65	75	75
20	40	50	50	65	65	75	75	90
25	40	50	50	65	75	90	90	100
40	40	50	65	65	75	90	100	100
50	50	65	75	75	90	100	115	125
65	40	50	65	75	90	100	115	125
75	50	65	75	90	100	115	125	140
100	65	75	90	100	115	125	140	150
125	65	75	100	115	125	140	150	165
150	65	90	100	115	125	150	165	180
200	65	90	115	125	140	165	180	190
250	75	100	115	140	150	180	190	205
300	75	100	125	150	165	190	205	215
350	90	115	140	150	180	190	215	230
400	90	115	140	165	180	205	230	240
450	90	125	140	165	190	215	230	255
500	100	125	150	180	205	215	240	255
600	100	125	150	190	205	230	255	280
700	100	140	165	190	215	240	265	290
750	115	140	165	190	230	240	265	290
900	115	150	180	205	230	255	280	305
Vert Flat	180	240	290	345	395	445	495	>510
Tk Top	190	240	290	345	395	445	495	>510
Tk Bot.	180	240	290	345	395	445	495	>510

Notes:
1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 25 W/m², whichever thickness is greater, at the conditions specified.
2. Thicknesses shown are applicable only to the conditions specified. Changing any condition, even slightly, can influence the required thickness.
3. All thicknesses are in millimetres.
4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for the specific system.
5. Thickness calculated using ASTM *Standard* C680-14 methodology.

- **Cellular glass** has excellent compressive strength, but it is rigid. Density varies between 98 and 136 kg/m³, but does not greatly affect thermal performance. It is fabricated for use 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. Cellular glass has very low water vapor permeability and water absorption; see information on vapor retarder systems in the section on Insulation System Moisture Resistance.
- **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. Although vapor permeability can be as low as 0.146 ng/(s·Pa·m), this is still significantly higher than the permeance requirement for vapor retarders [1.14 ng/(s·Pa·m²)]. For this reason, in refrigeration piping, flexible elastomeric should be used only with a vapor retarder applied to the exterior surface.
- **Closed-cell phenolic foam insulation** has a very low thermal conductivity, and can provide the same thermal performance as other insulations at a reduced thickness. Its density is 16 to 48 kg/m³. This material also has low flammability.
- **Polyisocyanurate insulation** has low thermal conductivity and excellent compressive strength. Density ranges from 29 to 96 kg/m³.
- **Extruded polystyrene (XPS) insulation** has good compressive strength. Typical density range is 24 to 32 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 transfer of water and water vapor into the system.

Vapor Retarders

Insulation materials should be protected by a continuous vapor retarder system with a maximum permeance of 1.14 ng/(s·Pa·m²), either integral to the insulation or as a separate vapor retarder material applied to the exterior surface of the insulation. At operating temperatures below −18°C, strongly consider requiring the vapor retarder to have a maximum permeance of 0.57 ng/(s·Pa·m²).

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 unsealed penetrations. It must be installed to allow expansion and contraction without compromising the vapor retarder's integrity. The

Table 5 Flexible Elastomeric Insulation Thickness for Indoor Design Conditions, mm

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

Nominal Pipe Size, mm	Pipe Operating Temperature, °C +4	−7	−18	−29	−40	−51	−62	−73
15	25	40	40	50	50	65	65	65
20	40	40	50	50	65	65	65	65
25	25	40	50	50	65	65	65	75
40	40	40	50	50	50	65	65	75
50	40	40	50	65	65	75	75	90
65	40	40	50	50	65	65	75	75
75	40	50	50	65	75	75	90	90
100	40	50	65	65	75	75	90	100
125	40	50	65	65	75	90	90	100
150	40	50	65	75	75	90	90	100
200	40	50	65	75	75	90	100	100
250	40	50	65	75	90	100	100	115
300	40	50	65	75	90	100	100	115
350	40	50	65	75	90	100	115	115
400	40	50	65	75	90	100	115	125
450	40	50	75	90	90	100	115	125
500	40	65	75	90	100	100	115	125
600	40	65	75	90	100	115	115	125
700	40	65	75	90	100	115	125	125
750	40	65	75	90	100	115	125	125
900	40	65	75	90	100	115	125	140
Vert Flat	50	65	75	90	115	125	140	150
Tk Top	40	65	75	90	115	125	140	150
Tk Bot.	50	65	75	90	115	125	140	150

Notes:
1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 25 W/m^2, whichever thickness is greater, at the conditions specified.
2. Thicknesses shown are applicable only to the conditions specified. Changing any condition, even slightly, can influence the required thickness.
3. All thicknesses are in millimetres.
4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for the specific system.
5. Thickness calculated using ASTM *Standard* C680-14 methodology.

Table 6 Flexible Elastomeric Insulation Thickness for Outdoor Design Conditions, mm

(38°C Ambient Temperature, 94% Relative Humidity, 0.1 Emittance, 12 km/h Wind Velocity.)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C +4	−7	−18	−29	−40	−51	−62	−73
15	40	40	50	50	65	65	65	75
20	40	50	50	65	65	65	75	90
25	40	40	50	65	65	75	90	90
40	40	50	50	65	75	90	90	100
50	40	50	65	75	90	100	100	115
65	40	50	65	75	90	100	100	115
75	50	65	75	90	100	115	125	125
100	50	65	75	100	115	115	125	140
125	65	75	90	100	115	125	140	150
150	65	75	90	115	125	140	150	165
200	65	90	100	115	140	150	165	180
250	75	90	115	125	150	165	180	190
300	75	100	115	140	150	180	190	205
350	75	100	125	140	165	180	205	215
400	90	100	125	150	180	190	205	230
450	90	115	140	150	180	205	215	230
500	90	115	140	165	190	205	230	240
600	90	125	150	180	190	215	240	255
700	100	125	150	180	205	230	255	265
750	100	125	150	180	205	230	255	280
900	100	140	165	190	215	240	265	290
Vert Flat	165	215	265	320	370	420	455	495
Tk Top	165	215	265	320	370	420	455	495
Tk Bot.	165	215	265	320	370	420	455	495

Notes:
1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 25 W/m^2, whichever thickness is greater, at the conditions specified.
2. Thicknesses shown are applicable only to the conditions specified. Changing any condition, even slightly, can influence the required thickness.
3. All thicknesses are in millimetres.
4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for the specific system.
5. Thickness calculated using ASTM *Standard* C680-14 methodology.

manufacturer should have specific design and installation instructions for their products.

Separate vapor retarder materials can be categorized into the following types:

- **Laminate material vapor retarders** consist of multiple layers of polymer film and aluminum foil laminated to one another and may also include reinforcing layers. This type is applied to the outer surface of the insulation by the manufacturer or fabricator, or in the field. Flat pieces of this material without any joints have a water vapor permeance of 0 ng/(s·Pa·m^2). This type has longitudinal and butt joints, so achieving a low system permeance depends on complete sealing of all joints and seams. Joints may be sealed with an adhesive applied to both overlapping surfaces, double-sided tape applied between two overlapping surfaces, or a single-sided tape applied over the joint between two mating surfaces. Manufacturers' instructions must be strictly followed during the installation. Materials in this category must be compliant with ASTM *Standard* C1775.
- **All-service jacket (ASJ) vapor retarders** are applied to the insulation surface by the manufacturer, fabricator, or in the field. This type of jacket has a low water vapor permeance under ideal conditions [1.14 ng/(s·Pa·m^2)]. These jackets have longitudinal joints and butt joints, so achieving low permeance depends on complete sealing of all joints and seams. Joints may be sealed with an adhesive applied to both overlapping surfaces, double-sided tape applied between two overlapping surfaces, or a single-sided tape applied over the joint between two mating surfaces. Manufacturers' instructions must be strictly followed during installation. Metal jacketing may damage ASJ jacketing, so use extra care when installing these together.

There are two types of ASJ vapor retarder. The **traditional ASJ** material has been available for many years and consists of laminated white paper, reinforcing glass fiber scrim, and aluminum foil. In **plasticized ASJ (pASJ)**, the paper layer is either replaced by or encapsulated by plastic. The traditional ASJ with exposed paper has service limitations on below-ambient systems in humid environments, such as those commonly encountered by insulation systems on refrigerant piping. In such situations, condensation can occur more frequently on the insulation's outer surface (e.g., when relative humidity exceeds 90%). The moisture-sensitive nature of paper and the relative frailty of uncoated aluminum foil can be problematic in the potentially high-humidity environment of unconditioned spaces with below-ambient applications. Exposure to water, either from condensation or from ambient sources, can cause degradation and distortion of the paper, higher likelihood of mold growth, and aluminum foil corrosion, leading to vapor retarder failure. The presence of leachable chloride can promote corrosion of the foil. With pASJ, the lack of exposed paper may reduce these concerns, but the layer of aluminum foil providing the vapor-retarding performance is still very thin and fragile. Also, cut edges expose any paper present, which could lead to wicking of water through this exposed paper into the interior of the pASJ.

Traditional ASJ vapor retarder with exposed paper is not recommended for use in refrigerant piping applications, regardless of pipe temperature or ambient environment. Plasticized ASJ could be acceptable in HVAC applications (see Chapter

Table 7 Closed-Cell Phenolic Foam Insulation Thickness for Indoor Design Conditions, mm

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

Nominal Pipe Size, mm	Pipe Operating Temperature, °C +4	−7	−18	−29	−40	−51	−62	−73
15	25	25	25	40	40	40	40	50
20	25	25	40	40	40	50	50	50
25	25	25	25	40	40	40	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	40	50	50
75	25	25	40	40	50	50	65	65
100	25	25	40	40	50	50	65	65
125	25	40	40	50	50	65	65	65
150	25	40	40	50	50	65	65	75
200	25	40	40	50	50	65	65	75
250	25	40	40	50	50	65	65	75
300	25	25	40	50	50	65	65	75
350	25	40	40	50	65	65	75	75
400	25	40	40	50	65	65	75	75
450	25	40	40	50	65	65	75	90
500	25	40	40	50	65	65	75	90
600	25	40	40	50	65	65	75	90
700	25	40	50	50	65	65	75	90
750	25	40	50	50	65	75	75	90
900	25	40	50	50	65	75	75	90
Vert Flat	25	40	50	50	65	75	90	90
Tk Top	25	40	50	50	65	75	90	90
Tk Bot.	25	40	50	50	65	75	90	90

Notes:
1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 25 W/m², whichever thickness is greater, at the conditions specified.
2. Thicknesses shown are applicable only to the conditions specified. Changing any condition, even slightly, can influence the required thickness.
3. All thicknesses are in millimetres.
4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for the specific system.
5. Thickness calculated using ASTM *Standard* C680-14 methodology.

Table 8 Closed-Cell Phenolic Foam Insulation Thickness for Outdoor Design Conditions, mm

(38°C Ambient Temperature, 94% Relative Humidity, 0.1 Emittance, 12 km/h Wind Velocity)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C +4	−7	−18	−29	−40	−51	−62	−73
15	25	25	40	40	40	40	50	50
20	25	40	40	40	40	50	50	50
25	25	25	40	40	40	50	50	65
40	25	25	40	40	50	50	50	65
50	25	40	40	50	50	65	65	75
65	25	40	40	40	50	50	65	75
75	25	40	50	50	65	65	75	90
100	40	40	50	65	65	75	75	90
125	40	50	50	65	75	75	90	100
150	40	50	50	65	75	90	90	100
200	40	50	65	65	75	90	100	115
250	40	50	65	75	90	100	115	125
300	40	50	65	75	90	100	115	125
350	50	65	75	90	100	115	125	140
400	50	65	75	90	100	115	125	140
450	50	65	75	90	115	125	140	150
500	50	65	75	100	115	125	140	150
600	50	75	90	100	115	125	150	165
700	65	75	90	100	125	140	150	165
750	65	75	90	115	125	140	150	180
900	65	75	100	115	125	150	165	180
Vert Flat	90	125	150	180	215	240	265	305
Tk Top	90	125	150	180	215	240	280	305
Tk Bot.	90	125	150	180	215	240	265	305

Notes:
1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 25 W/m², whichever thickness is greater, at the conditions specified.
2. Thicknesses shown are applicable only to the conditions specified. Changing any condition, even slightly, can influence the required thickness.
3. All thicknesses are in millimetres.
4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for the specific system.
5. Thickness calculated using ASTM *Standard* C680-14 methodology.

23 in the 2021 *ASHRAE Handbook—Fundamentals*) but has questionable performance in refrigerant piping applications and should only be used in nondemanding situations such as higher pipe temperatures (greater than −18°C) and pipes in conditioned spaces where the relative humidity is controlled so that it does not exceed 50%.

Both ASJ and pASJ are typically the lowest-cost vapor retarder alternatives, so they often are used by the contractor or fabricator unless explicitly specified otherwise. Specifiers, engineers, and facility owners should make an informed decision on allowable vapor retarder types and should not leave selection of the vapor retarder to the contractor or fabricator, because this is too likely to lead to the inappropriate use of ASJ or pASJ in refrigeration applications.

- **Coatings**, **mastics**, and **heavy, paint-type products** applied by trowel, brush, or spraying, are available for covering insulation. Material permeability is a function of the thickness applied, so this must be very carefully controlled and monitored during installation. Some products are recommended for indoor use only, whereas others can be used indoors or outdoors. These products may impart odors, and manufacturers' instructions should be meticulously followed. Ensure that 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 retarder continuity.
- A **modified asphalt or butyl rubber membrane retarder,** consisting of a rubberized layer adhered to a plastic film, is also an acceptable and commonly used vapor retarder. This type of retarder has a low permeance of ≤1.14 ng/(s·Pa·m²). 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 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, depends on thickness, and ranges from 0.57 to 1.14 ng/(s·Pa·m²). 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, double-sided tape applied between two overlapping surfaces, or various adhesives.

Weather Barrier Jacketing

Weather barrier jacketing on insulated pipes and vessels protects the vapor retarder system and insulation from weather, ultraviolet (UV) light, and physical abuse. Various plastic and metallic products are available for this purpose. Some specifications suggest that the jacketing should 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,

Table 9 Polyisocyanurate Foam Insulation Thickness for Indoor Design Conditions, mm

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

Nominal Pipe Size, mm	Pipe Operating Temperature, °C +4	−7	−18	−29	−40	−51	−62	−73
15	25	25	40	40	40	50	50	50
20	25	40	40	40	50	50	50	65
25	25	25	40	40	50	50	50	65
40	25	25	40	50	50	50	50	65
50	25	40	40	50	50	65	65	65
65	25	40	40	40	50	50	65	65
75	25	40	40	50	50	65	65	75
100	25	40	40	50	65	65	75	75
125	25	40	50	50	65	65	75	75
150	25	40	50	50	65	75	75	90
200	25	40	50	50	65	75	75	90
250	25	40	50	50	65	75	75	90
300	25	40	50	50	65	75	90	90
350	25	40	50	65	75	75	90	100
400	25	40	50	65	75	75	90	100
450	25	40	50	65	75	75	90	100
500	25	40	50	65	75	75	90	100
600	25	40	50	65	75	90	90	100
700	25	40	50	65	75	90	90	100
750	25	40	50	65	75	90	90	100
900	25	40	50	65	75	90	100	100
Vert Flat	40	40	50	65	75	90	100	115
Tk Top	25	40	50	65	75	90	100	115
Tk Bot.	40	40	50	65	75	90	100	115

Notes:
1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 25 W/m², whichever thickness is greater, at the conditions specified.
2. Thicknesses shown are applicable only to the conditions specified. Changing any condition, even slightly, can influence the required thickness.
3. All thicknesses are in millimetres.
4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for the specific system.
5. Thickness calculated using ASTM *Standard* C680-14 methodology.

Table 10 Polyisocyanurate Foam Insulation Thickness for Outdoor Design Conditions, mm

(38°C Ambient Temperature, 94% Relative Humidity, 0.1 Emittance, 12 km/h Wind Velocity)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C +4	−7	−18	−29	−40	−51	−62	−73
15	25	40	40	40	50	50	50	65
20	25	40	40	50	50	50	65	65
25	25	40	40	40	50	65	65	75
40	25	40	40	50	50	65	65	75
50	25	40	50	50	65	75	75	90
65	40	40	40	50	65	75	75	90
75	40	40	50	65	75	90	90	100
100	40	50	65	75	75	90	100	115
125	40	50	65	75	90	100	100	115
150	50	50	65	75	90	100	115	125
200	50	65	75	90	100	115	125	140
250	50	65	75	90	115	125	140	150
300	50	65	90	100	115	125	140	165
350	50	75	90	100	125	140	150	165
400	65	75	90	115	125	140	165	180
450	65	75	100	115	125	150	165	180
500	65	75	100	115	140	150	180	190
600	65	90	100	125	140	165	180	205
700	65	90	115	125	150	165	190	205
750	75	90	115	125	150	180	190	215
900	75	90	115	140	165	180	205	230
Vert Flat	115	150	190	230	265	305	345	380
Tk Top	115	150	190	230	265	305	345	380
Tk Bot.	115	150	190	230	265	305	345	380

Notes:
1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 25 W/m², whichever thickness is greater, at the conditions specified.
2. Thicknesses shown are applicable only to the conditions specified. Changing any condition, even slightly, can influence the required thickness.
3. All thicknesses are in millimetres.
4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for the specific system.
5. Thickness calculated using ASTM *Standard* C680-14 methodology.

or any other items that puncture should not be used because they will compromise the vapor retarder system. 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 physical damage. The protective jacketing must be installed independently and in addition to any factory- or field-applied vapor retarder. Ambient-temperature cycling causes the jacketing to expand and contract. The manufacturer's instructions should show how to install the jacketing to allow this expansion and contraction.

Metal jacketing may be smooth, textured, embossed, or corrugated aluminum or stainless steel with a minimum 0.076 mm thick polysurlyn moisture barrier factory-heat-laminated to the interior surface (Young 2011). Note that this moisture barrier applied to the metal jacketing helps prevent jacket and pipe corrosion; it does not serve as a vapor retarder to prevent water vapor from entering the insulation system. Metallic jackets are recommended for all outdoor piping.

Protective jacketing is required whenever piping is exposed to washing, physical abuse, or traffic. White polyvinyl chloride (PVC) (minimum 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 of PVC jacketing should be seal welded using a solvent welding adhesive. 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 intermediate joints no more than 6 m apart. Where very heavy abuse and/or hot, scalding washdowns are encountered, a chlorinated polyvinyl chloride (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 minimum 0.41 mm (for embossed or smooth aluminum) or 0.76 mm (for CPVC) thick jacketing. On vertical and 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 Type 304 stainless) and spaced every 300 mm. Jacketing on valves and fittings should match that of the adjacent piping.

See ASTM *Standards* C1729-17 and C1767-16a for additional information on selecting and specifying aluminum and stainless steel jacketing for insulation, respectively.

5. 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. Before installing 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.
- Pipe should be dry and free from condensate or frost.

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

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+4	−7	−18	−29	−40	−51	−62	−73
15	25	40	40	40	50	50	65	65
20	25	40	40	50	50	65	65	65
25	25	40	40	50	50	65	65	65
40	25	40	50	50	50	50	65	65
50	25	40	50	50	65	65	75	75
65	40	40	40	50	50	65	65	75
75	40	40	50	65	65	75	75	90
100	40	40	50	65	65	75	75	90
125	40	50	50	65	75	75	90	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	65	75	90	100	100
350	40	50	65	75	90	90	100	115
400	40	50	65	75	90	90	100	115
450	40	50	65	75	90	100	100	115
500	40	50	65	75	90	100	100	115
600	40	50	65	75	90	100	115	115
700	40	50	65	75	90	100	115	115
750	40	50	65	75	90	100	115	115
900	40	50	65	75	90	100	115	125
Vert Flat	40	50	75	90	100	115	125	140
Tk Top	40	50	75	90	100	115	125	140
Tk Bot.	40	50	75	90	100	115	125	140

Notes:
1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 25 W/m^2, whichever thickness is greater, at the conditions specified.
2. Thicknesses shown are applicable only to the conditions specified. Changing any condition, even slightly, can influence the required thickness.
3. All thicknesses are in millimetres.
4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for the specific system.
5. Thickness calculated using ASTM *Standard* C680-14 methodology.

Table 12 Extruded Polystyrene (XPS) Foam Insulation Thickness for Outdoor Design Conditions, mm
(38°C Ambient Temperature, 94% Relative Humidity, 0.1 Emittance, 12 km/h Wind Velocity)

Nominal Pipe Size, mm	Pipe Operating Temperature, °C							
	+4	−7	−18	−29	−40	−51	−62	−73
15	40	40	40	50	50	65	65	65
20	40	40	50	50	65	65	65	75
25	40	40	50	50	65	65	75	90
40	40	50	50	50	65	75	75	90
50	40	50	65	65	75	90	100	100
65	40	50	50	65	75	90	90	100
75	50	65	65	75	90	100	115	115
100	50	65	75	90	100	115	115	125
125	50	65	75	90	100	115	125	140
150	50	75	90	100	115	125	140	150
200	65	75	90	100	125	140	150	165
250	65	90	100	115	125	150	165	180
300	65	90	100	125	140	150	180	190
350	75	90	115	125	150	165	180	190
400	75	100	115	140	150	180	190	205
450	75	100	125	140	165	180	190	215
500	75	100	125	150	165	190	205	215
600	90	115	140	150	180	190	215	230
700	90	115	140	165	180	205	230	240
750	90	115	140	165	190	205	230	240
900	100	125	150	180	205	215	240	265
Vert Flat	150	205	240	290	330	370	405	445
Tk Top	150	205	240	290	330	370	405	445
Tk Bot.	150	205	240	290	330	370	405	445

Notes:
1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 25 W/m^2, whichever thickness is greater, at the conditions specified.
2. Thicknesses shown are applicable only to the conditions specified. Changing any condition, even slightly, can influence the required thickness.
3. All thicknesses are in millimetres.
4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for the specific system.
5. Thickness calculated using ASTM *Standard* C680-14 methodology.

- 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 for the pipe and must be fully vapor sealed, including vapor sealing to adjoining vapor barrier (VB) jackets. The following guidelines also apply:

- If 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. 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, except for 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 retarder installed. When specified, at least one coat of vapor retarder mastic should be applied the same day. If applying the first coat is impractical, 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, and anchors, and at all locations requiring potential maintenance, such as valves, flanges, and instrumentation connections to piping or equipment. All vapor stops must also seal the annular space between pipe and pipe insulation at the vapor stop location. 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 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 spaced a maximum of 230 mm apart and applied with a 50% circumferential overlap. Single and outer layers more than 450 mm in diameter and inner layers with radiused and beveled segments should be secured by minimum 9.5 mm wide stainless steel bands spaced on 230 mm maximum centers. 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 reinforcing mesh fabric should be laid smoothly into the mastic or finish and thoroughly embedded in the coating. Be careful not to rupture the weave. The

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 *Standard* B31.1
[a]Spacing does not apply where span calculations are made or where concentrated loads are placed between supports such as flanges, valves, specialties, etc.
[b]Suggested maximum spacing between pipe supports for horizontal straight runs of standard and heavier pipe.

Table 14 Shield/Saddle Dimensions for Insulated Pipe and Tubing

Nominal Outside Insulation Diameter,* mm	Shield Thickness, gage (mm)	Shield Arc Length, mm	Shield Length, mm	Nominal 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	205
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 IIAR (2000) *Ammonia Refrigeration Handbook.*
Note: Support shield gages listed are for use with band-type hangers only. For point loading, increase shield thickness and length.
*Insulation size tolerances can influence fit of a metal shield/saddle to outer surface of insulation system. For more information, see ASTM *Standard* C585.

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

[a]Mean COLTE between 21 and –70°C from *Perry's Chemical Engineer's Handbook*, 7th ed., Table 10-52.
[b]COLTE between 20 and 100°C from *Perry's Chemical Engineer's Handbook*, 7th ed., Table 28-4.

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 reinforcing mesh fabric with a smooth, unbroken surface. The total thickness of mastic or finish should follow the coating manufacturer's recommendation for low-permeance applications.

Pipe Supports and Hangers. When possible, the pipe hanger or support should be located outside of the vapor retarder system and jacketing. 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 of the insulation system surrounds the pipe.

ASME *Standard* B31.5 establishes basic stress allowances for piping material. Loading on the insulation material is a function of its compressive strength. Table 13 suggests spacing for pipe supports. Related information is also in Chapter 46 of the 2020 *ASHRAE Handbook—HVAC Systems and Equipment*.

Insulation material may not have sufficient compressive resistance to support loading at these support spacings, so force from 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/saddles or cradles between the band or hanger and the insulation. Although the shields/saddles are typically rolled to wrap the outer diameter of the insulation in a 180° arc, the bearing area is calculated over a 120° arc of the outer circumference of the insulation multiplied by the shield/saddle 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/saddle length. In this case, rolled plate may be more suitable than lesser-thickness sheet metal. Make provisions to secure the shield/saddle on both sides of the hanger (metal band), and center the shield/saddle in the support. Table 14 lists lengths and thicknesses for pipe shields/saddles.

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 insulation.
2. Tightly pack break with fibrous insulation material.
3. Secure insulation on either side of joint with stainless steel bands that have been hand tightened.
4. Cover joint with appropriate properly sealed sheet/film vapor retarder or vapor retarder mastic.

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:

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

where

S = worst-case maximum spacing of contraction joints, m
T_i = temperature during insulation installation, °C
T_o = coldest service temperature of pipe, °C
α_i = coefficient of linear thermal expansion (COLTE) of insulation material, mm/(m·K)
α_p = COLTE of pipe material, mm/(m·K)
L = pipe length, m
d = amount of expansion or contraction that can be absorbed by each insulation contraction joint, mm

Table 15 provides COLTEs for various pipe and insulation materials. The values can be used in this equation as α_i and α_p.

6. MAINTENANCE OF INSULATION SYSTEMS

Periodic inspections of refrigerant piping systems are needed to determine the presence of moisture, which degrades an insulation system's thermal efficiency, promotes corrosion under insulation (CUI), and shortens its service life, and to identify any damaged areas of the insulation system so that proper maintenance can be conducted. The frequency of inspection should be determined by the critical nature of the process, external environment, and age of the insulation. A *routine* inspection should check for the following:

- Signs of moisture or ice on lower part of horizontal pipe, at bottom elbow of a vertical pipe, and around pipe hangers and saddles (moisture may migrate to low areas)
- Mechanical damage and jacketing penetrations, openings, or separations
- Evidence of corrosion on the metal jacketing
- Looseness of banding on jacketing
- CUI, particularly on couplings (e.g., groove and clamp bolts)
- Bead caulking failure, especially around flange and valve covers
- Loss of jacketing integrity and open seams around all intersecting points (e.g., pipe transitions, branches, tees)
- Cloth visible through mastic or finish if pipe is protected by a reinforced mastic weather barrier

An *extensive* inspection should also include the following:

- Using thermographic or radiographic equipment to identify areas of concern.
- Designing a method to repair, close, and seal any cut in insulation or vapor retarder to maintain a positive seal throughout the entire system.
- Examining pipe surface for corrosion if insulation is wet.

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

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