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"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. " ASHRAE 2017 Handbook

Clearly the intent of protection is independent of the pipe insulation as such the surface of the insulation cannot meet the protection or vapor retarder requirements as put forward in the 45 day language of Section 120.3 . California took the language from 90.1 standard on pipe insulation protection into its Energy standard in 2005
Changes have been made to the language to write it into performance language that can be effectuality enforced . the current 45 day language is confusing and miss the intent of the standard that protection and vapor retarding be independent of the insulation to maintain the insulation systems thermal conductivity and allow for maintenance to insure performance and reduce cost.

Additional submitted attachment is included below.

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 35 to −100°F. It does not deal with HVAC systems or applications such as chilled-water systems. Refer to Chapters 23, 25, 26, and 27 in the 2017 *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, 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 (e.g., 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 the manufacturers' recommendations.

DESIGN CONSIDERATIONS FOR BELOW-AMBIENTREFRIGERANT 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* C680-10 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 differ 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 8 $Btu/h \cdot ft^2$ 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, low-permeance vapor retarder to limit the amount of vapor entering the insulation.

Various insulation and accessory materials are used in systems for refrigerant piping. Successful system designs specify the best solution for material selection, installation procedures, operations, and maintenance to achieve long-term satisfactory performance, meeting all criteria imposed by the owner, 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 *Standard* C335. However, this method is generally run only at above-ambient conditions, making it of little use for below-ambient applications. In most cases, for below-ambient conditions, thermal conductivity is determined on flat specimens (using ASTM *Standard* C177 or 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 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 the perm, and data are determined by ASTM *Standard* E96. As with thermal conductivity, permeance can vary with conditions. Data for most insulation materials are determined at room temperature using *Standard* E96's desiccant method (procedure A). 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 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 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 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. In this instance, the possible 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 a 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.

Insulation System Water Resistance

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 35°F or lower, the problem may be severe.

If a continuous low-permeance vapor retarder is properly installed on the insulation system and is not damaged in any way, then the insulation material's water resistance is not as important. In practice, it is very difficult to achieve and maintain perfect performance and continuity in a vapor retarder. Therefore, the water resistance of the insulation material 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 35°F.

INSULATION SYSTEMS

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

- Pipe or surface preparation
- Insulation material
- Insulation joint sealant/adhesive
- 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 installation of 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.

Insulated carbon steel and stainless steel surfaces that operate continuously below 25°F or 140°F, respectively, 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 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 the following:

- 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 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 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 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, pressurized refrigerant leaks from the line.

ESCC occurs in the presence of the following:

- 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) to allow 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; for example, applying stress to align a copper tube with a fitting or physically damaging the copper before installation.
- 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. 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 steel piping and equipment when chlorides in the environment or insulation material are transported in the presence of water to the hot stainless steel surface and are then concentrated by evaporation of the water. 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 chlorides, to the metal surface.

Table 1. Protective Coating Systems for Carbon Steel Piping

Substrate	Temperature Range	Surface Prep.[d]	Surface Profile	Prime Coat[a]	Intermediate Coat[a]	Finish Coat[a]
Carbon Steel System No.1	−50 to 140°F	NACE *Standard* 2	0.002 to 0.003 in.	0.005 in. high-build (HB) epoxy	N/A	0.005 in. HB epoxy
Carbon Steel System No.2	−50 to 140°F	NACE *Standard* 2	0.002 to 0.004 in.	0.007 to 0.010 in. metallized aluminum	0.0005 to 0.00075 in. of MIL-P-24441/1[b] epoxy polyamide (EPA) followed by 0.003 in. of MIL-P-24441/1[c] EPA	0.003 in. of MIL-P-24441/2[c] EPA
Carbon Steel System No.3	200°F maximum	NACE *Standard* 2	0.002 to 0.003 in.	0.002 to 0.003 in. moisture-cured urethane aluminum primer	0.002 to 0.003 in. moisture-cured micaceous aluminum	Two 0.003 in. coats of acrylic urethane
Carbon Steel System No.3	−50 to 300°F	NACE *Standard* 2	0.002 to 0.003 in.	0.006 in. epoxy/phenolic or high-temperature rated amine-cured coal tar epoxy	N/A	0.006 in. epoxy/phenolic or high-temperature-rated amine-cured coal tar epoxy

[a] Coating thicknesses are typical dry film values.

[b] MIL-P-24441, Part 1.

[c] MIL-P-24441, Part 2.

[d] NACE *Standard* 2/SSPC-SP 10

Most ESCC failures occur when metal temperature is in the hot-water range of 140 to 300°F. Below 140°F, 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, chloride salts dissolved in the water concentrate on the surface.

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

Updates to Insulation Thicknesses Tables. Most insulation thickness calculation tools use the calculation methodology in ASTM *Standard* C680. In 2010, this standard was updated to include a substantially different, superior method for calculating the convective component of the outer surface coefficient. This coefficient is critical to determining the surface temperature of an insulation system, so it strongly affects any insulation thickness calculation that depends on surface temperature such as condensation control or personnel protection. When updating this chapter's insulation thickness tables, TC 10.3 had the following goals:

- Determine all insulation thicknesses using the latest *Standard* C680 methodology.
- Use the latest thermal conductivity curves from the appropriate ASTM material standard for each insulation material.
- Maintain the same design criteria used in the 2010 chapter (condensation control and 8 $Btu/h \cdot ft^2$ heat gain limit).
- Continue the practice of not including any safety factor in the condensation control calculations.
- Use the correct emittance for aluminum jacketing of 0.1 as specified in ASTM *Standard* C1729.
- Maintain the same design conditions used in the 2010 chapter except for relative humidity and jacket emittance.
- Because the 2010 insulation thicknesses were acceptable in the field, minimize changes from the 2010 chapter to insulation thicknesses in the tables.

To accomplish the last goal for the outdoor condition tables, the design relative humidity was increased until the overall insulation thickness changes to the tables were minimized. This occurred at a relative humidity of 94%. For the indoor tables, heat gain controls the required thickness, so increasing the relative humidity would have no consequence. Because the 8 $Btu/h \cdot ft^2$ heat gain limit is firmly set in the industry, it was deemed inappropriate to modify this design criterion. Insulation thicknesses in the indoor tables were therefore allowed to deviate based on only the first four goals. The preceding approach is particularly acceptable because each table is clearly identified as being applicable to the specified conditions.

Guidelines. 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.

Cellular glass, closed-cell phenolic, flexible elastomeric, polyisocyanurate, and extruded 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 to 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 6.3 and 8.6 lb/ft^3, 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.
- **Flexible elastomerics** are soft and flexible. This material is suitable for use on nonrigid tubing, and its density ranges from 3.0 to 8.5 lb/ft^3. Although vapor permeability can be as low as 0.1 perm inch, this is still significantly higher than the requirement for vapor retarders (0.02 perm). 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 2.0 to 3.0 lb/ft^3. This material also has low flammability.
- **Polyisocyanurate insulation** has low thermal conductivity and excellent compressive strength. Density ranges from 1.8 to 6.0 lb/ft^3.
- **Extruded polystyrene (XPS) insulation** has good compressive strength. Typical density range is 1.5 to 2.0 lb/ft^3.

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.

Table 2. Properties of Insulation Materials[d]

	Cellular Glass	Flexible Elastomeric	Closed-Cell Phenolic	Polyisocyanurate	Extruded Polystyrene (XPS)
Standard that specifies material and temperature requirements	ASTM C552	ASTM C534	ASTM C1126	ASTM C591	ASTM C578 Type XIII
Suitable temp. range, °F	−450 to 800	−70 to 220	−297 to 257	−297 to 300	−297 to 165
Flame spread rating[a]	5	25	25	25	5
Smoke developed rating[a]	0	50	50	55	165
Water vapor permeability,[b] per m-inches	0.005	0.1	5.0	4.0	1.5
Thermal conductivity,[c] Btu · in/h · ft² · °F					
At 0°F mean temperature	0.27	0.26	0.15	0.19	0.22
At +75°F mean temperature	0.31	0.28	0.15	0.19	0.26
At +120°F mean temperature	0.34	0.30	0.18	0.21	0.28

[a] Tested in accordance with ASTM *Standard* E84 for 1 in. thick insulation.

[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 in accordance with ASTM *Standard* C177 or C518.

[d] Most physical properties shown are taken from ASTM consensus standards listed and represent requirements at specific laboratory conditions. It is the responsibility of the design engineer to ensure suitability of material under actual use conditions.

Table 3. Cellular Glass Insulation Thickness for Indoor Design Conditions (90°F Ambient Temperature, 80% Relative Humidity, 0.9 Emittance, 0 mph Wind Velocity)

Nominal Pipe Size, in.	Pipe Operating Temperature, ˚F							
	−100	−80	−60	−40	−20	0	20	40
0.50	2.5	2.5	2.5	2.0	2.0	1.5	1.5	1.0
0.75	3.0	2.5	2.5	2.5	2.0	2.0	1.5	1.0
1.00	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.0
1.50	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.0
2.00	3.5	3.5	3.0	2.5	2.5	2.0	1.5	1.0
2.50	3.5	3.0	3.0	2.5	2.5	2.0	1.5	1.0
3.00	4.0	3.5	3.5	3.0	2.5	2.0	1.5	1.0
4.00	4.0	3.5	3.5	3.0	2.5	2.0	1.5	1.0
5.00	4.0	4.0	3.5	3.0	2.5	2.0	1.5	1.5
6.00	4.0	4.0	3.5	3.5	3.0	2.0	2.0	1.5
8.00	4.5	4.0	4.0	3.5	3.0	2.0	2.0	1.5
10.00	4.5	4.5	4.0	3.5	3.0	2.0	2.0	1.5
12.00	5.0	4.5	4.0	3.5	3.0	2.0	2.0	1.5
14.00	5.0	4.5	4.5	4.0	3.5	2.5	2.0	1.5
16.00	5.0	4.5	4.5	4.0	3.5	2.5	2.0	1.5
18.00	5.0	5.0	4.5	4.0	3.5	3.0	2.5	2.0
20.00	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0
24.00	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0
28.00	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0
30.00	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0
36.00	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0
Vert. flat	6.5	6.0	5.0	4.5	4.0	3.5	2.5	2.0
Tank top	6.5	6.0	5.0	4.5	4.0	3.5	2.5	2.0
Tank bottom	6.5	6.0	5.0	4.5	4.0	3.5	2.5	2.0

Notes:

1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 8 Btu/h · ft^2, whichever thickness is greater, at specified conditions.

Nominal Pipe Size, in.	Pipe Operating Temperature, ˚F							
	–100	–80	–60	–40	–20	0	20	40

2. Thicknesses shown are applicable only to specified conditions. Changing any condition, even slightly, can influence required thickness.

3. All thicknesses are in inches.

4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for specific systems.

5. Thickness calculated using ASTM *Standard* C680-10 methodology.

Vapor Retarders

Insulation materials should be protected by a continuous vapor retarder with a maximum permeance of 0.02 perm, either integral to the insulation or as a vapor retarder material applied to the exterior surface of the insulation. At operating temperatures below 0˚F, strongly consider requiring the vapor retarder to have a maximum permeance of 0.01 perm.

Table 4. Cellular Glass Insulation Thickness for Outdoor Design Conditions (100˚F Ambient Temperature, 94% Relative Humidity, 0.1 Emittance, 7.5 mph Wind Velocity)

Nominal Pipe Size, in.	Pipe Operating Temperature, ˚F							
	–100	–80	–60	–40	–20	0	20	40
0.50	3.0	3.0	2.5	2.5	2.5	2.0	1.5	1.5
0.75	3.5	3.0	3.0	2.5	2.5	2.0	2.0	1.5
1.00	4.0	3.5	3.5	3.0	2.5	2.0	2.0	1.5
1.50	4.0	4.0	3.5	3.0	2.5	2.5	2.0	1.5
2.00	5.0	4.5	4.0	3.5	3.0	3.0	2.5	2.0
2.50	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5
3.00	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0
4.00	6.0	5.5	5.0	4.5	4.0	3.5	3.0	2.5
5.00	6.5	6.0	5.5	5.0	4.5	4.0	3.0	2.5
6.00	7.0	6.5	6.0	5.0	4.5	4.0	3.5	2.5
8.00	7.5	7.0	6.5	5.5	5.0	4.5	3.5	2.5
10.00	8.0	7.5	7.0	6.0	5.5	4.5	4.0	3.0
12.00	8.5	8.0	7.5	6.5	6.0	5.0	4.0	3.0

Nominal Pipe Size, in.	Pipe Operating Temperature, °F							
	−100	−80	−60	−40	−20	0	20	40
14.00	9.0	8.5	7.5	7.0	6.0	5.5	4.5	3.5
16.00	9.5	9.0	8.0	7.0	6.5	5.5	4.5	3.5
18.00	10	9.0	8.5	7.5	6.5	5.5	5.0	3.5
20.00	10	9.5	8.5	8.0	7.0	6.0	5.0	4.0
24.00	11	10	9.0	8.0	7.5	6.0	5.0	4.0
28.00	11	10.5	9.5	8.5	7.5	6.5	5.5	4.0
30.00	11.5	10.5	9.5	9.0	7.5	6.5	5.5	4.5
36.00	12	11	10	9.0	8.0	7.0	6.0	4.5
Vert. flat	>20	19.5	17.5	15.5	13.5	11.5	9.5	7.0
Tank top	>20	19.5	17.5	15.5	13.5	11.5	9.5	7.5
Tank bottom	>20	19.5	17.5	15.5	13.5	11.5	9.5	7.0

Notes:

1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 8 Btu/h · ft^2, whichever thickness is greater, at specified conditions.

2. Thicknesses shown are applicable only to specified conditions. Changing any condition, even slightly, can influence required thickness.

3. All thicknesses are in inches.

4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for specific systems.

5. Thickness calculated using ASTM *Standard* C680-10 methodology.

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 to allow expansion and contraction without compromising the vapor retarder’s integrity. 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 insulation surface by the manufacturer or in the field. This type of jacket has a low water vapor permeance under ideal conditions (0.02 perms). These jackets have longitudinal joints and butt joints, so achieving low permeability depends on complete sealing of all joints and seams. Jackets may be sealed with a contact adhesive applied to both overlapping surfaces. Manufacturers' instructions must be strictly followed during installation. Butt joints are sealed similarly 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 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. Material permeability is a function of the thickness applied, and 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 2 in. 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 2 in. overlap to maintain retarder continuity.

Table 5. Flexible Elastomeric Insulation Thickness for Indoor Design Conditions (90˚F Ambient Temperature, 80% Relative Humidity, 0.9 Emittance, 0 mph Wind Velocity)

	Pipe Operating Temperature, ˚F							
Nominal Pipe Size, in.	−100	−80	−60	−40	−20	0	20	40
0.50	2.5	2.5	2.5	2.0	2.0	1.5	1.5	1.0
0.75	2.5	2.5	2.5	2.5	2.0	2.0	1.5	1.5
1.00	3.0	2.5	2.5	2.5	2.0	2.0	1.5	1.0
1.50	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5
2.00	3.5	3.0	3.0	2.5	2.5	2.0	1.5	1.5
2.50	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.5
3.00	3.5	3.5	3.0	3.0	2.5	2.0	2.0	1.5
4.00	4.0	3.5	3.0	3.0	2.5	2.5	2.0	1.5
5.00	4.0	3.5	3.5	3.0	2.5	2.5	2.0	1.5

Nominal Pipe Size, in.	Pipe Operating Temperature, ˚F							
	−100	−80	−60	−40	−20	0	20	40
6.00	4.0	3.5	3.5	3.0	3.0	2.5	2.0	1.5
8.00	4.0	4.0	3.5	3.0	3.0	2.5	2.0	1.5
10.00	4.5	4.0	4.0	3.5	3.0	2.5	2.0	1.5
12.00	4.5	4.0	4.0	3.5	3.0	2.5	2.0	1.5
14.00	4.5	4.5	4.0	3.5	3.0	2.5	2.0	1.5
16.00	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5
18.00	5.0	4.5	4.0	3.5	3.5	3.0	2.0	1.5
20.00	5.0	4.5	4.0	4.0	3.5	3.0	2.5	1.5
24.00	5.0	4.5	4.5	4.0	3.5	3.0	2.5	1.5
28.00	5.0	5.0	4.5	4.0	3.5	3.0	2.5	1.5
30.00	5.0	5.0	4.5	4.0	3.5	3.0	2.5	1.5
36.00	5.5	5.0	4.5	4.0	3.5	3.0	2.5	1.5
Vert. flat	6.0	5.5	5.0	4.5	3.5	3.0	2.5	2.0
Tank top	6.0	5.5	5.0	4.5	3.5	3.0	2.5	1.5
Tank bottom	6.0	5.5	5.0	4.5	3.5	3.0	2.5	2.0

Notes:

1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 8 Btu/h · ft^2, whichever thickness is greater, at specified conditions.

2. Thicknesses shown are applicable only to specified conditions. Changing any condition, even slightly, can influence required thickness.

3. All thicknesses are in inches.

4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for specific systems.

5. Thickness calculated using ASTM *Standard* C680-10 methodology.

- 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 0.015 perms. Some solvent-based adhesives can attack this vapor retarder. All joints should have a 2 in. 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 0.002 to 0.006 in. Its permeance is very low, depends on thickness, and ranges from 0.01 to 0.02 perms. Some solvent-based adhesives can attack this vapor retarder. All joints should have a 1 to 2 in. overlap to ensure adequate sealing and can be sealed with tapes made from the same film or various adhesives.

Table 6. Flexible Elastomeric Insulation Thickness for Outdoor Design Conditions (100˚F Ambient Temperature, 94% Relative Humidity, 0.1 Emittance, 7.5 mph Wind Velocity)

	Pipe Operating Temperature, ˚F							
Nominal Pipe Size, in.	–100	–80	–60	–40	–20	0	20	40
0.50	3.0	2.5	2.5	2.5	2.0	2.0	1.5	1.5
0.75	3.5	3.0	2.5	2.5	2.5	2.0	2.0	1.5
1.00	3.5	3.5	3.0	2.5	2.5	2.0	1.5	1.5
1.50	4.0	3.5	3.5	3.0	2.5	2.0	2.0	1.5
2.00	4.5	4.0	4.0	3.5	3.0	2.5	2.0	1.5
2.50	4.5	4.0	4.0	3.5	3.0	2.5	2.0	1.5
3.00	5.0	5.0	4.5	4.0	3.5	3.0	2.5	2.0
4.00	5.5	5.0	4.5	4.5	4.0	3.0	2.5	2.0
5.00	6.0	5.5	5.0	4.5	4.0	3.5	3.0	2.5
6.00	6.5	6.0	5.5	5.0	4.5	3.5	3.0	2.5
8.00	7.0	6.5	6.0	5.5	4.5	4.0	3.5	2.5
10.00	7.5	7.0	6.5	6.0	5.0	4.5	3.5	3.0
12.00	8.0	7.5	7.0	6.0	5.5	4.5	4.0	3.0
14.00	8.5	8.0	7.0	6.5	5.5	5.0	4.0	3.0
16.00	9.0	8.0	7.5	7.0	6.0	5.0	4.0	3.5
18.00	9.0	8.5	8.0	7.0	6.0	5.5	4.5	3.5
20.00	9.5	9.0	8.0	7.5	6.5	5.5	4.5	3.5
24.00	10.0	9.5	8.5	7.5	7.0	6.0	5.0	3.5
28.00	10.5	10.0	9.0	8.0	7.0	6.0	5.0	4.0
30.00	11.0	10.0	9.0	8.0	7.0	6.0	5.0	4.0
36.00	11.5	10.5	9.5	8.5	7.5	6.5	5.5	4.0

Nominal Pipe Size, in.	Pipe Operating Temperature, ˚F							
	–100	–80	–60	–40	–20	0	20	40
Vert. flat	19.5	18.0	16.5	14.5	12.5	10.5	8.5	6.5
Tank top	19.5	18.0	16.5	14.5	12.5	10.5	8.5	6.5
Tank bottom	19.5	18.0	16.5	14.5	12.5	10.5	8.5	6.5

Notes:

1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 8 Btu/h · ft^2, whichever thickness is greater, at specified conditions.

2. Thicknesses shown are applicable only to specified conditions. Changing any condition, even slightly, can influence required thickness.

3. All thicknesses are in inches.

4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for specific systems.

5. Thickness calculated using ASTM *Standard* C680-10 methodology.

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, 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.

Table 7. Closed-Cell Phenolic Foam Insulation Thickness for Indoor Design Conditions (90˚F Ambient Temperature, 80% Relative Humidity, 0.9 Emittance, 0 mph Wind Velocity)

Nominal Pipe Size, in.	Pipe Operating Temperature, ˚F							
	−100	−80	−60	−40	−20	0	20	40
0.50	2.0	1.5	1.5	1.5	1.5	1.0	1.0	1.0
0.75	2.0	2.0	2.0	1.5	1.5	1.5	1.0	1.0
1.00	2.0	2.0	1.5	1.5	1.5	1.0	1.0	1.0
1.50	2.0	2.0	2.0	1.5	1.5	1.5	1.0	1.0
2.00	2.5	2.0	2.0	1.5	1.5	1.5	1.0	1.0
2.50	2.0	2.0	1.5	1.5	1.5	1.5	1.0	1.0
3.00	2.5	2.5	2.0	2.0	1.5	1.5	1.0	1.0
4.00	2.5	2.5	2.0	2.0	1.5	1.5	1.0	1.0
5.00	2.5	2.5	2.5	2.0	2.0	1.5	1.5	1.0
6.00	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.0
8.00	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.0
10.00	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.0
12.00	3.0	2.5	2.5	2.0	2.0	1.5	1.0	1.0
14.00	3.0	3.0	2.5	2.5	2.0	1.5	1.5	1.0
16.00	3.0	3.0	2.5	2.5	2.0	1.5	1.5	1.0
18.00	3.5	3.0	2.5	2.5	2.0	1.5	1.5	1.0
20.00	3.5	3.0	2.5	2.5	2.0	1.5	1.5	1.0
24.00	3.5	3.0	2.5	2.5	2.0	1.5	1.5	1.0
28.00	3.5	3.0	2.5	2.5	2.0	1.5	1.5	1.0
30.00	3.5	3.0	3.0	2.5	2.0	2.0	1.5	1.0
36.00	3.5	3.0	3.0	2.5	2.0	2.0	1.5	1.0
Vert. flat	3.5	3.5	3.0	2.5	2.0	2.0	1.5	1.0
Tank top	3.5	3.5	3.0	2.5	2.0	2.0	1.5	1.0
Tank bottom	3.5	3.5	3.0	2.5	2.0	2.0	1.5	1.0

Notes:

Nominal Pipe Size, in.	Pipe Operating Temperature, °F							
	–100	–80	–60	–40	–20	0	20	40

1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 8 Btu/h · ft^2, whichever thickness is greater, at specified conditions.

2. Thicknesses shown are applicable only to specified conditions. Changing any condition, even slightly, can influence required thickness.

3. All thicknesses are in inches.

4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for specific systems.

5. Thickness calculated using ASTM *Standard* C680-10 methodology.

Metal jacketing may be smooth, textured, embossed, or corrugated aluminum or stainless steel with a minimum 3 mil thick multilayer 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 0.03 in. 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 20 ft 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 225°F, whereas standard PVC will warp and disfigure at 140°F.

Table 8. Closed-Cell Phenolic Foam Insulation Thickness for Outdoor Design Conditions (100°F Ambient Temperature, 94% Relative Humidity, 0.1 Emittance, 7.5 mph Wind Velocity)

Nominal Pipe Size, in.	Pipe Operating Temperature, °F							
	–100	–80	–60	–40	–20	0	20	40
0.50	2.0	2.0	1.5	1.5	1.5	1.5	1.0	1.0
0.75	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.0
1.00	2.5	2.0	2.0	1.5	1.5	1.5	1.0	1.0
1.50	2.5	2.0	2.0	2.0	1.5	1.5	1.0	1.0

Nominal Pipe Size, in.	Pipe Operating Temperature, °F							
	−100	−80	−60	−40	−20	0	20	40
2.00	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.0
2.50	3.0	2.5	2.0	2.0	1.5	1.5	1.5	1.0
3.00	3.5	3.0	2.5	2.5	2.0	2.0	1.5	1.0
4.00	3.5	3.0	3.0	2.5	2.5	2.0	1.5	1.5
5.00	4.0	3.5	3.0	3.0	2.5	2.0	2.0	1.5
6.00	4.0	3.5	3.5	3.0	2.5	2.0	2.0	1.5
8.00	4.5	4.0	3.5	3.0	3.0	2.5	2.0	1.5
10.00	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5
12.00	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5
14.00	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0
16.00	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0
18.00	6.0	5.5	5.0	4.5	3.5	3.0	2.5	2.0
20.00	6.0	5.5	5.0	4.5	4.0	3.0	2.5	2.0
24.00	6.5	6.0	5.0	4.5	4.0	3.5	3.0	2.0
28.00	6.5	6.0	5.5	5.0	4.0	3.5	3.0	2.5
30.00	7.0	6.0	5.5	5.0	4.5	3.5	3.0	2.5
36.00	7.0	6.5	6.0	5.0	4.5	4.0	3.0	2.5
Vert. flat	12.0	10.5	9.5	8.5	7.0	6.0	5.0	3.5
Tank top	12.0	11.0	9.5	8.5	7.0	6.0	5.0	3.5
Tank bottom	12.0	10.5	9.5	8.5	7.0	6.0	5.0	3.5

Notes:

1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 8 Btu/h · ft^2, whichever thickness is greater, at specified conditions.

2. Thicknesses shown are applicable only to specified conditions. Changing any condition, even slightly, can influence required thickness.

3. All thicknesses are in inches.

4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for specific systems.

5. Thickness calculated using ASTM *Standard* C680-10 methodology.

Roof piping should be jacketed with a minimum 0.016 in. aluminum (embossed or smooth finish, depending on aesthetic choice). On vertical and pitched lines, this jacketing should be installed with a minimum 2 in. overlap arranged to shed any water in the direction of the pitch. Only stainless steel bands should be used to install this jacketing (1/2 in. wide by 0.02 in. thick304 stainless) and spaced every 12 in. Jacketing on valves and fittings should match that of the adjacent piping.

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

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. 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 for the pipe and must be fully vapor sealed. 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 barrier 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.

Table 9. Polyisocyanurate Foam Insulation Thickness for Indoor Design Conditions (90˚F Ambient Temperature, 80% Relative Humidity, 0.9 Emittance, 0 mph Wind Velocity)

	Pipe Operating Temperature, ˚F							
Nominal Pipe Size, in.	–100	–80	–60	–40	–20	0	20	40
0.50	2.0	2.0	2.0	1.5	1.5	1.5	1.0	1.0
0.75	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.0
1.00	2.5	2.0	2.0	2.0	1.5	1.5	1.0	1.0
1.50	2.5	2.0	2.0	2.0	2.0	1.5	1.0	1.0
2.00	2.5	2.5	2.5	2.0	2.0	1.5	1.5	1.0
2.50	2.5	2.5	2.0	2.0	1.5	1.5	1.5	1.0
3.00	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.0
4.00	3.0	3.0	2.5	2.5	2.0	1.5	1.5	1.0
5.00	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.0
6.00	3.5	3.0	3.0	2.5	2.0	2.0	1.5	1.0
8.00	3.5	3.0	3.0	2.5	2.0	2.0	1.5	1.0
10.00	3.5	3.0	3.0	2.5	2.0	2.0	1.5	1.0
12.00	3.5	3.5	3.0	2.5	2.0	2.0	1.5	1.0
14.00	4.0	3.5	3.0	3.0	2.5	2.0	1.5	1.0
16.00	4.0	3.5	3.0	3.0	2.5	2.0	1.5	1.0
18.00	4.0	3.5	3.0	3.0	2.5	2.0	1.5	1.0
20.00	4.0	3.5	3.0	3.0	2.5	2.0	1.5	1.0
24.00	4.0	3.5	3.5	3.0	2.5	2.0	1.5	1.0
28.00	4.0	3.5	3.5	3.0	2.5	2.0	1.5	1.0

Nominal Pipe Size, in.	Pipe Operating Temperature, °F –100	–80	–60	–40	–20	0	20	40
30.00	4.0	3.5	3.5	3.0	2.5	2.0	1.5	1.0
36.00	4.0	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Vert. flat	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.5
Tank top	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Tank bottom	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.5

Notes:

1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 8 Btu/h · ft^2, whichever thickness is greater, at specified conditions.

2. Thicknesses shown are applicable only to specified conditions. Changing any condition, even slightly, can influence required thickness.

3. All thicknesses are in inches.

4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for specific systems.

5. Thickness calculated using ASTM *Standard* C680-10 methodology.

Table 10. Polyisocyanurate Foam Insulation Thickness for Outdoor Design Conditions (100°F Ambient Temperature, 94% Relative Humidity, 0.1 Emittance, 7.5 mph Wind Velocity)

Nominal Pipe Size, in.	Pipe Operating Temperature, °F –100	–80	–60	–40	–20	0	20	40
0.50	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.0
0.75	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.0
1.00	3.0	2.5	2.5	2.0	1.5	1.5	1.5	1.0
1.50	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.0
2.00	3.5	3.0	3.0	2.5	2.0	2.0	1.5	1.0
2.50	3.5	3.0	3.0	2.5	2.0	1.5	1.5	1.5
3.00	4.0	3.5	3.5	3.0	2.5	2.0	1.5	1.5
4.00	4.5	4.0	3.5	3.0	3.0	2.5	2.0	1.5
5.00	4.5	4.0	4.0	3.5	3.0	2.5	2.0	1.5

Nominal Pipe Size, in.	Pipe Operating Temperature, °F							
	–100	–80	–60	–40	–20	0	20	40
6.00	5.0	4.5	4.0	3.5	3.0	2.5	2.0	2.0
8.00	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0
10.00	6.0	5.5	5.0	4.5	3.5	3.0	2.5	2.0
12.00	6.5	5.5	5.0	4.5	4.0	3.5	2.5	2.0
14.00	6.5	6.0	5.5	5.0	4.0	3.5	3.0	2.0
16.00	7.0	6.5	5.5	5.0	4.5	3.5	3.0	2.5
18.00	7.0	6.5	6.0	5.0	4.5	4.0	3.0	2.5
20.00	7.5	7.0	6.0	5.5	4.5	4.0	3.0	2.5
24.00	8.0	7.0	6.5	5.5	5.0	4.0	3.5	2.5
28.00	8.0	7.5	6.5	6.0	5.0	4.5	3.5	2.5
30.00	8.5	7.5	7.0	6.0	5.0	4.5	3.5	3.0
36.00	9.0	8.0	7.0	6.5	5.5	4.5	3.5	3.0
Vert. flat	15.0	13.5	12.0	10.5	9.0	7.5	6.0	4.5
Tank top	15.0	13.5	12.0	10.5	9.0	7.5	6.0	4.5
Tank bottom	15.0	13.5	12.0	10.5	9.0	7.5	6.0	4.5

Notes:

1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 8 Btu/h · ft^2, whichever thickness is greater, at specified conditions.

2. Thicknesses shown are applicable only to specified conditions. Changing any condition, even slightly, can influence required thickness.

3. All thicknesses are in inches.

4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for specific systems.

5. Thickness calculated using ASTM *Standard* C680-10 methodology.

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. 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 10 ft on straight runs.

Securing Insulation. When applicable, the innermost layer of insulation should be applied in two half-sections and secured with 3/4 in. wide pressure-sensitive filament tape spaced a maximum of 9 in. apart and applied with a 50% circumferential overlap. Single and outer layers more than 18 in. in diameter and inner layers with radiused and beveled segments should be secured by a minimum 3/8 in. wide stainless steel bands spaced on 9 in. 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 glass fiber reinforcing mesh should be laid smoothly into the mastic or finish and thoroughly embedded in the coating. Take care not to rupture the weave. The fabric should be overlapped a minimum of 2 in. at joints to provide strength equal to that maintained elsewhere.

Table 11. Extruded Polystyrene (XPS) Insulation Thickness for Indoor Design Conditions (90˚F Ambient Temperature, 80% Relative Humidity, 0.9 Emittance, 0 mph Wind Velocity)

	Pipe Operating Temperature, ˚F							
Nominal Pipe Size, in.	–100	–80	–60	–40	–20	0	20	40
0.50	2.5	2.5	2.0	2.0	1.5	1.5	1.5	1.0
0.75	2.5	2.5	2.5	2.0	2.0	1.5	1.5	1.0
1.00	2.5	2.5	2.5	2.0	2.0	1.5	1.5	1.0
1.50	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.0
2.00	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.0
2.50	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.5
3.00	3.5	3.0	3.0	2.5	2.5	2.0	1.5	1.5
4.00	3.5	3.0	3.0	2.5	2.5	2.0	1.5	1.5
5.00	3.5	3.5	3.0	3.0	2.5	2.0	2.0	1.5
6.00	3.5	3.5	3.0	3.0	2.5	2.0	2.0	1.5
8.00	4.0	3.5	3.0	3.0	2.5	2.5	2.0	1.5
10.00	4.0	3.5	3.5	3.0	2.5	2.5	2.0	1.5
12.00	4.0	4.0	3.5	3.0	2.5	2.5	2.0	1.5
14.00	4.5	4.0	3.5	3.5	3.0	2.5	2.0	1.5

	Pipe Operating Temperature, ˚F							
Nominal Pipe Size, in.	−100	−80	−60	−40	−20	0	20	40
16.00	4.5	4.0	3.5	3.5	3.0	2.5	2.0	1.5
18.00	4.5	4.0	4.0	3.5	3.0	2.5	2.0	1.5
20.00	4.5	4.0	4.0	3.5	3.0	2.5	2.0	1.5
24.00	4.5	4.5	4.0	3.5	3.0	2.5	2.0	1.5
28.00	4.5	4.5	4.0	3.5	3.0	2.5	2.0	1.5
30.00	4.5	4.5	4.0	3.5	3.0	2.5	2.0	1.5
36.00	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5
Vert. flat	5.5	5.0	4.5	4.0	3.5	3.0	2.0	1.5
Tank top	5.5	5.0	4.5	4.0	3.5	3.0	2.0	1.5
Tank bottom	5.5	5.0	4.5	4.0	3.5	3.0	2.0	1.5

Notes:

1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 8 Btu/h · ft^2, whichever thickness is greater, at specified conditions.

2. Thicknesses shown are applicable only to specified conditions. Changing any condition, even slightly, can influence required thickness.

3. All thicknesses are in inches.

4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for specific systems.

5. Thickness calculated using ASTM *Standard* C680-10 methodology.

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 mastic or finish should follow 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 of the insulation system surrounds the pipe.

ASME *Standard* B31.1 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 2016 *ASHRAE Handbook–HVAC Systems and Equipment*.

Table 12. Extruded Polystyrene (XPS) Insulation Thickness for Outdoor Design Conditions (100˚F Ambient Temperature, 94% Relative Humidity, 0.1 Emittance, 7.5 mph Wind Velocity)

	Pipe Operating Temperature, ˚F							
Nominal Pipe Size, in.	**−100**	**−80**	**−60**	**−40**	**−20**	**0**	**20**	**40**
0.50	2.5	2.5	2.5	2.0	2.0	1.5	1.5	1.5
0.75	3.0	2.5	2.5	2.5	2.0	2.0	1.5	1.5
1.00	3.5	3.0	2.5	2.5	2.0	2.0	1.5	1.5
1.50	3.5	3.0	3.0	2.5	2.0	2.0	2.0	1.5
2.00	4.0	4.0	3.5	3.0	2.5	2.5	2.0	1.5
2.50	4.0	3.5	3.5	3.0	2.5	2.0	2.0	1.5
3.00	4.5	4.5	4.0	3.5	3.0	2.5	2.5	2.0
4.00	5.0	4.5	4.5	4.0	3.5	3.0	2.5	2.0
5.00	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0
6.00	6.0	5.5	5.0	4.5	4.0	3.5	3.0	2.0
8.00	6.5	6.0	5.5	5.0	4.0	3.5	3.0	2.5
10.00	7.0	6.5	6.0	5.0	4.5	4.0	3.5	2.5
12.00	7.5	7.0	6.0	5.5	5.0	4.0	3.5	2.5
14.00	7.5	7.0	6.5	6.0	5.0	4.5	3.5	3.0
16.00	8.0	7.5	7.0	6.0	5.5	4.5	4.0	3.0
18.00	8.5	7.5	7.0	6.5	5.5	5.0	4.0	3.0
20.00	8.5	8.0	7.5	6.5	6.0	5.0	4.0	3.0
24.00	9.0	8.5	7.5	7.0	6.0	5.5	4.5	3.5
28.00	9.5	9.0	8.0	7.0	6.5	5.5	4.5	3.5
30.00	9.5	9.0	8.0	7.5	6.5	5.5	4.5	3.5
36.00	10.5	9.5	8.5	8.0	7.0	6.0	5.0	4.0
Vert. flat	17.5	16.0	14.5	13.0	11.5	9.5	8.0	6.0
Tank top	17.5	16.0	14.5	13.0	11.5	9.5	8.0	6.0
Tank bottom	17.5	16.0	14.5	13.0	11.5	9.5	8.0	6.0

Nominal Pipe Size, in.	Pipe Operating Temperature, °F							
	–100	–80	–60	–40	–20	0	20	40

Notes:

1. Insulation thickness shown is that required to prevent condensation on outside jacket surface or limit heat gain to 8 Btu/h · ft^2, whichever thickness is greater, at specified conditions.

2. Thicknesses shown are applicable only to specified conditions. Changing any condition, even slightly, can influence required thickness.

3. All thicknesses are in inches.

4. Values do not include safety factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for specific systems.

5. Thickness calculated using ASTM *Standard* C680-10 methodology.

Insulation material may or may not have the compressive strength to support loading at these distances. Therefore, 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 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 a 180° arc, 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 lengths 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 1 in. 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 vapor retarder and seal properly.

Table 13. Suggested Pipe Support Spacing for Straight Horizontal Runs

Nominal Pipe OD, in.	Standard Steel Pipe[a],[b]	Copper Tube
	Support Spacing, ft	
1/2	6	5
3/4	6	5
1	6	6
1 1/2	10	8
2	10	8
2 1/2	11	9
3	12	10
4	14	12
6	16	–
8	16	–
10	16	–
12	16	–
14	16	–
16	16	–
18	16	–
20	16	–
24	16	–

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 Dimensions for Insulated Pipe and Tubing

Insulation Diameter, in.	Shield Thickness, gage (in.)	Shield Arc Length, in.	Shield Length, in.	Shield Radius, in.
2.5	20 (0.036)	2.5	12	1.25
3	20 (0.036)	3	12	1.5
3.5	18 (0.048)	3.5	12	1.75

Insulation Diameter, in.	Shield Thickness, gage (in.)	Shield Arc Length, in.	Shield Length, in.	Shield Radius, in.
4	18 (0.048)	4	12	2
4.5	18 (0.048)	5	12	2.25
5	16 (0.060)	5.5	12	2.5
6	16 (0.060)	6.5	12	3
8	16 (0.060)	8.5	18	4
10	14 (0.075)	10.5	18	5
12	14 (0.075)	12.5	18	6
14	14 (0.075)	14.5	18	7
16	12 (0.105)	19	18	8
20	12 (0.105)	21	18	10
22	12 (0.105)	23	18	11
24	12 (0.105)	25	18	12
26	12 (0.105)	27	18	13
28	12 (0.105)	29.5	18	14
30	12 (0.105)	31.5	18	15

Source: Adapted from IIAR (2004) *Ammonia Refrigeration Handbook.*

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

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, ft

T_i = temperature during insulation installation, °F

T_o = coldest service temperature of pipe, °F

α_i = coefficient of linear thermal expansion (COLTE) of insulation material, in/ft·°F

α_p = COLTE of the pipe material, in/ft·°F

L = pipe length, ft

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

Table 15 provides COLTEs for various pipe and insulation materials. The values can be used in this 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 degrades an insulation system's thermal efficiency 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 include the following checks:

- Look for 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).
- Look for mechanical damage and jacketing penetrations, openings, or separations.
- Look for evidence of corrosion on the metal jacketing.
- Check jacketing to determine whether 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 mastic or finish if pipe is protected by a reinforced mastic weather barrier.

Table 15. COLTE Values for Various Materials

Material	**COLTE,[a] in/ft·°F**
Pipe	
Carbon steel	6.78×10^{-5}
Stainless steel	10.5×10^{-5}
Aluminum	13.5×10^{-5}

Material	COLTE,[a] in/ft · °F
Ductile iron	6.1×10^{-5}
Copper[b]	11.3×10^{-5}
Insulation	
Cellular glass	4.0×10^{-5}
Flexible elastomeric	N/A
Closed-cell phenolic	34×10^{-5}
Polyisocyanurate	60×10^{-5}
Polystyrene	42×10^{-5}

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

[b] COLTE between 68 and 212°F from *Perry's Chemical Engineer's Handbook,* 7th ed., Table 28-4.

An *extensive* inspection should also include the following:

- Use thermographic or radiographic equipment to isolate areas of concern.
- Design a method to repair, close, and seal any cut in insulation or vapor retarder to maintain a positive seal throughout the entire system.
- Examine 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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