Standard Guide for Industrial Thermal Insulation Systems[1]

This standard is issued under the fixed designation C1696; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers information on selection of insulation materials, systems design, application methods, protective coverings, guarantees, inspection, testing, and maintenance of thermal insulation primarily for industrial applications in a temperature range of –320 to 1200°F (–195.5 to 648.8°C).

1.2 This guide is intended to provide practical guidelines, by applying acceptable current practice while indicating the basic principles by which new materials can be assessed and adapted for use under widely differing conditions. Design engineers, the general contractors, the fabricators, and the insulation contractors will find this guide helpful.

1.3 Although some insulation system designs can serve as fire protection, this guide does not address the criteria specific to that need. API 521 Guide for Pressure-Relieving and Depressuring Systems is recommended as a reference for fire protection. This guide will however address the fire properties of insulation materials.

1.4 This guide is not intended for commercial, architectural, acoustical, marine, vehicle transport, or military use.

1.5 This guide does not address insulation system design for refractory linings or cold boxes whereby these are typically package units and of a proprietary insulation design.

1.6 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A167 Specification for Stainless and Heat-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip (Withdrawn 2014)[3]

A240/A240M Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications

A653/A653M Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process

A792/A792M Specification for Steel Sheet, 55 % Aluminum-Zinc Alloy-Coated by the Hot-Dip Process

B209 Specification for Aluminum and Aluminum-Alloy Sheet and Plate

C165 Test Method for Measuring Compressive Properties of Thermal Insulations

C167 Test Methods for Thickness and Density of Blanket or Batt Thermal Insulations

C168 Terminology Relating to Thermal Insulation

C177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus

C195 Specification for Mineral Fiber Thermal Insulating Cement

C203 Test Methods for Breaking Load and Flexural Properties of Block-Type Thermal Insulation

C209 Test Methods for Cellulosic Fiber Insulating Board

C240 Test Methods of Testing Cellular Glass Insulation Block

C272/C272M Test Method for Water Absorption of Core Materials for Sandwich Constructions

C302 Test Method for Density and Dimensions of Preformed Pipe-Covering-Type Thermal Insulation

C303 Test Method for Dimensions and Density of Preformed Block and Board–Type Thermal Insulation

C335/C335M Test Method for Steady-State Heat Transfer

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[1] This guide is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.40 on Insulation Systems.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

Properties of Pipe Insulation
C351 Test Method for Mean Specific Heat of Thermal Insulation (Withdrawn 2008)[3]
C356 Test Method for Linear Shrinkage of Preformed High-Temperature Thermal Insulation Subjected to Soaking Heat
C411 Test Method for Hot-Surface Performance of High-Temperature Thermal Insulation
C446 Test Method for Breaking Load and Calculated Modulus of Rupture of Preformed Insulation for Pipes (Withdrawn 2002)[3]
C447 Practice for Estimating the Maximum Use Temperature of Thermal Insulations
C449 Specification for Mineral Fiber Hydraulic-Setting Thermal Insulating and Finishing Cement
C450 Practice for Fabrication of Thermal Insulating Fitting Covers for NPS Piping, and Vessel Lagging
C518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
C533 Specification for Calcium Silicate Block and Pipe Thermal Insulation
C534/C534M Specification for Preformed Flexible Elastomeric Cellular Thermal Insulation in Sheet and Tubular Form
C547 Specification for Mineral Fiber Pipe Insulation
C552 Specification for Cellular Glass Thermal Insulation
C553 Specification for Mineral Fiber Blanket Thermal Insulation for Commercial and Industrial Applications
C578 Specification for Rigid, Cellular Polystyrene Thermal Insulation
C591 Specification for Unfaced Preformed Rigid Cellular Polyisocyanurate Thermal Insulation
C592 Specification for Mineral Fiber Blanket Insulation and Blanket-Type Pipe Insulation (Metal-Mesh Covered) (Industrial Type)
C610 Specification for Molded Expanded Perlite Block and Pipe Thermal Insulation
C612 Specification for Mineral Fiber Block and Board Thermal Insulation
C665 Specification for Mineral-Fiber Blanket Thermal Insulation for Light Frame Construction and Manufactured Housing
C680 Practice for Estimate of the Heat Gain or Loss and the Surface Temperatures of Insulated Flat, Cylindrical, and Spherical Systems by Use of Computer Programs
C692 Test Method for Evaluating the Influence of Thermal Insulations on External Stress Corrosion Cracking Tendency of Austenitic Stainless Steel
C795 Specification for Thermal Insulation for Use in Contact with Austenitic Stainless Steel
C871 Test Methods for Chemical Analysis of Thermal Insulation Materials for Leachable Chloride, Fluoride, Silicate, and Sodium Ions
C1029 Specification for Spray-Applied Rigid Cellular Polyurethane Thermal Insulation
C1055 Guide for Heated System Surface Conditions that Produce Contact Burn Injuries
C1104/C1104M Test Method for Determining the Water Vapor Sorption of Unfaced Mineral Fiber Insulation
C1126 Specification for Faced or Unfaced Rigid Cellular Phenolic Thermal Insulation
C1139 Specification for Fibrous Glass Thermal Insulation and Sound Absorbing Blanket and Board for Military Applications
C1289 Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board
C1393 Specification for Perpendicularly Oriented Mineral Fiber Roll and Sheet Thermal Insulation for Pipes and Tanks
C1427 Specification for Extruded Preformed Flexible Cellular Polyolefin Thermal Insulation in Sheet and Tubular Form
C1511 Test Method for Determining the Water Retention (Repellency) Characteristics of Fibrous Glass Insulation (Aircraft Type)
C1559 Test Method for Determining Wicking of Fibrous Glass Blanket Insulation (Aircraft Type)
C1617 Practice for Quantitative Accelerated Laboratory Evaluation of Extraction Solutions Containing Ions Leached from Thermal Insulation on Aqueous Corrosion of Metals
C1775 Specification for Laminate Protective Jacket and Tape for Use over Thermal Insulation for Outdoor Applications
D1621 Test Method for Compressive Properties of Rigid Cellular Plastics
D1622/D1622M Test Method for Apparent Density of Rigid Cellular Plastics
D2126 Test Method for Response of Rigid Cellular Plastics to Thermal and Humid Aging
D2842 Test Method for Water Absorption of Rigid Cellular Plastics
D3574 Test Methods for Flexible Cellular Materials—Slab, Bonded, and Molded Urethane Foams
E84 Test Method for Surface Burning Characteristics of Building Materials
E96/E96M Test Methods for Water Vapor Transmission of Materials
E136 Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C
E176 Terminology of Fire Standards
E659 Test Method for Autoignition Temperature of Chemicals
E2652 Test Method for Behavior of Materials in a Tube Furnace with a Cone-shaped Airflow Stabilizer, at 750°C

2.2 *API Standard:*
API 521 Guide for Pressure-Relieving and Depressuring Systems[4]

2.3 *NACE Standard:*

SP0198 Standard Practice—The Control of Corrosion Under Thermal Insulation and Fireproofing Materials—A System Approach[5]

2.4 *NFPA Standards:*[6]

NFPA 49 Hazardous Chemicals Data

NFPA 90A Standard for the Installation of Air Conditioning and Ventilating Systems

NFPA 259 Standard Test Method for Potential Heat of Building Materials

2.5 *Federal Standard:*

40 CFR 60 Protection of Environment—Standards of Performance for New Stationary Sources[7]

3. Terminology

3.1 *Definitions*—Terminology C168 is recommended to provide definitions and information on symbols, units, and abbreviations of terms used in ASTM standards pertaining to thermal insulation materials and materials associated with them. Terminology E176 is recommended to provide terms and standard definitions for fire standards. Any term used in this guide that is not defined in Terminology C168 or E176 will be defined in the section in which the term is used.

3.2 *Acronyms:*

ACM	=	asbestos-containing materials
ACT	=	autoignition temperature
ASJ	=	all service jacket
CPVC	=	chlorinated polyvinyl chloride
DFT	=	dry film thickness
EPA	=	Environmental Protection Agency
FRP	=	fiberglass-reinforced plastic
FSI/SDI	=	flame spread index/smoke developed index
MSDS	=	material safety data sheet
NAIMA	=	North American Insulation Manufacturers Association
NDT	=	nondestructive testing
NFPA	=	National Fire Protection Association
OSHA	=	Occupational Safety and Health Administration
PVC	=	polyvinyl chloride
QA/QC	=	quality assurance/quality control
SS	=	stainless steel
UV	=	ultraviolet
WVT	=	water vapor transmission

4. Significance and Use

4.1 When choosing a thermal insulation product or combination of products, physical, chemical and mechanical properties and the significance of those properties should be considered. ASTM test methods are usually performed under laboratory conditions and may not accurately represent field conditions depending on process temperature, environment, and operating conditions. Performance results obtained using ASTM test methods can be used to determine compliance of materials to specifications but do not necessarily predict installed performance. Values stated in the ASTM material standards are those that apply to the majority of materials and not to any specific product; other tested values may exist for specific material applications.

4.2 Design of thermal insulation systems requires the understanding of process requirements, temperature control, heat loss criteria, control of thermal shock, and mechanical forces on insulation generated by thermal gradients and wind environmental conditions. Sometimes, the mechanical design of piping and equipment needs to be modified to support insulation adequately and provide for insulation weatherproofing. Process requirements may dictate the control of critical temperature to prevent freezing, maintain viscosity, or minimize internal corrosion. When handling heat transfer fluids such as ethylene oxide or hot oils, the selection of insulation materials and the insulation system design becomes critical. whereby If these fluids are absorb in insulation materials, the fluid flash point could be below the fluid operating temperature. Specified heat gain or heat loss and acceptable surface temperatures could also dictate thermal design of insulation systems. Environmental corrosivity, high wind, and extreme ambient temperatures affect the selection of weatherproofing and methods of its securement. A combination of these factors plays a significant role in the selection of insulation materials and application methods to provide long-lasting trouble-free service.

4.3 Application methods are generally defined by the purchaser's specifications. However, some specialty insulation systems, such as prefabricated insulation panels for ductwork, precipitators, and tanks, will also have supplemental installation requirements specified by the insulation system manufacturer. defined by the specification of the manufacturer.

4.4 In any application of thermal insulation, the insulation requires protection of some type, be it protection from the elements such as rain, snow, sleet, wind, ultraviolet solar radiation, protection from external forces that can cause mechanical damage, vapor passage, fire, chemical attack, or any combination of these. This protection can be provided in by metal, plastic, coated or laminated composites or both, mastic coatings, or a combination of the above depending upon the application, service, and economic requirements. Considering the enormous overall cost of a new facility, and comparing the initial cost of the insulated portion as a small percentage of that overall cost with the substantially increased operating cost as a result of inefficient insulation protection, it is common sense to provide only the best insulation system available and the best protection for that long-term investment consistent with the appropriate design and economic requirements. Usually a new facility is very expensive and the initial cost of the insulation portion is a small percentage of that overall cost. However, increased operating costs can result from inefficient protection.

[4] Available from American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, http://www.api.org.

[5] Available from NACE International (NACE), 1440 South Creek Dr., Houston, TX 77084-4906, http://www.nace.org.

[6] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, http://www.nfpa.org.

[7] Available from the U.S. Government Printing Office, Superintendent of Documents, 732 N. Capital St., NW, Washington, DC 20402-0001.

4.5 Bid invitations should contain information necessary to determine how guarantees of materials and application will be resolved.

4.6 It is recommended that the purchaser provide a quality assurance program that defines the inspection of all materials, material safety data sheets (MSDS), and specific application procedures before and during progress of the insulation work.

4.7 During contract negotiations, the contractor and purchaser should discuss and agree to the procedures to be adopted for suitable periodic inspection and maintenance of the insulation systems to ensure that the initial performance of the material will be maintained. And, where applicable, they should agree to the methods of repair and replacement to be adopted in case damage occurs during service or overhaul.

5. Significant Physical Properties of Thermal Insulation Materials

5.1 *Apparent Thermal Conductivity:*

5.1.1 The apparent thermal conductivity of an insulation material is the measure of its ability to conduct heat between the hot and cold surfaces of the insulation. In inch pound units, this property (which is also known as the "k" factor of "k" value) is expressed as the amount of heat that passes through a unit area of a unit thickness of a homogeneous substance in a specified amount of time for a unit temperature difference, Btu-in/ft^2-hr-F (In SI units, this property is expressed in W/m-K). Thermal conductivity of insulation changes with mean temperature:

$$\text{Mean temperature} = (\text{inner surface temp} + \text{outer surface temp})/2 \quad (1)$$

5.1.1.1 In general, thermal conductivity of insulation increases with an increase in mean temperature. Therefore, when determining the required insulation thickness for a process temperature, thermal conductivity at the process temperature must be considered. This is best determined by a computer program such as ASTM C680. curve from that process temperature to the jacket temperature must be considered. Since this is difficult to accomplish using hand calculations, it is recommended that computer programs designed to account for this be used.

5.1.2 There are several different ASTM tests available for determining the thermal conductivity of materials depending on the temperature range and the geometry. of the sample. Some of these are Test Method C177 referred to as the guarded hot plate and Test Method C518 referred to as the heat flow meter. Both of these tests are for block or flat insulations. Test Method C335/C335M is used for horizontal pipe insulation. The cylindrical shape of pipe insulation and the presence of a longitudinal joint in the pipe insulation can may cause the apparent thermal conductivity of the pipe insulation to be 20 % or higher than different from that for a flat, one-solid-piece configuration. Also the orientation of the insulation, vertical versus horizontal, will affect the surface coefficient of the insulation, and hence, the heat loss.

5.2 *Autoignition:*

5.2.1 Some fluids such as oxygen and some heat transfer fluids when absorbed in insulation could lower the autoignition temperature. Autoignition is the initiation of combustion of a material in air as the result of heat liberation caused by an exothermic oxidation reaction in the absence of an external ignition source such as a spark or flame. The autoignition temperature (ACT) is the lowest temperature to which a combustible mixture should be raised so that the rate of heat evolved by the exothermic oxidation reaction is greater than the rate of heat loss to the surroundings and causes ignition. Autoignition depends on specific mixtures of chemicals and the method and apparatus used for its determination. It also depends on the volume and geometry of the containing vessel, the insulation material, and the initial temperature and pressure of the mixture and the surroundings.

5.2.2 Published autoignition temperatures (NFPA 49, for example) are specific to the method of determination (Test Method E659) and may not be interpolated or extrapolated for different configurations. It is improper to state that an insulation material has the property to "suppress an autoignition temperature" of a chemical. When a chemical has access to an insulated assembly from an external or internal leak, the chemical may be between the outer covering and the insulation, in the insulation, in joints and seams between insulation segments, or between the insulation and the vessel. The autoignition temperature for such a situation is most likely to be lower than published data, but that difference may not be attributed to the composition of an insulation material. No quantitative change can be predicted without testing the configuration. The engineer or designer should know how to design insulated systems for materials such as heat transfer oils, petroleum oils, or hazardous chemicals and consider the need to eliminate leakage sources, installation details of protective insulation coverings, and the selection of an insulating material.

5.3 *Coefficient of Thermal Expansion/Contraction:*

5.3.1 The coefficient of thermal expansion (contraction) is the material property that measures the material's dimensional change relative to a change in its temperature. When heated or cooled, materials, such as steel, will expand or contract at a constant rate. These changes (see 7.2.4.7) are reversible in some materials and will return to their original dimension when their temperature returns to where it was before being heated or cooled. This reversibility distinguishes coefficient of expansion (contraction) from the other two properties relating to dimensional changes: dimensional stability and linear shrinkage, neither of which is reversible. Not all insulation materials exhibit this reversibility property.

5.3.2 Coefficients of expansion need to be considered when designing insulation system expansion and contraction joints. The amount of movement that can be accommodated by an expansion joint, along with the differential movement between the insulation and the substrate, is needed when determining the expansion/contraction joints spacing.

5.4 *Combustion Characteristics:*

5.4.1 In some industrial applications insulation materials are required to be noncombustible. When a material is required to be noncombustible it usually must pass the requirements of Test Method E136. In Test Method E136 materials are exposed to very high temperatures (1382°F or 750°C).

TABLE 1 Typical ASTM Specifications for Min/Max Values of Some Insulation Materials Used for Industrial Applications

NOTE 1—Values represent a majority of known materials. Not all materials of the same classification may have the same values. All values should be verified with the material manufacturer before use.

NOTE 2—Verify value with the material manufacturer.

NOTE 3—See Specification C610 for water absorption test and limits. Contact the manufacturer for product data.

NOTE 4—Contact the material manufacturer for Test Method C411 test results when using above 250°F (121°C). Heat rise or fall (change) should be in a linear progression not to exceed a rate of 200°F (111°C) per hour.

NOTE 5—Value varies with type and density. Contact the manufacturer.

NOTE 6—Value is at ambient temperature. Contact the manufacturer for temperatures above ambient.

NOTE 7—Consult the manufacturer for specific recommendation and properties at temperatures less than -40°F (4.4°C).

NOTE 8—Response to thermal aging per Test Method D2126.

NOTE 9—Response to thermal aging per Test Method D2126. Maximum 4 %.

NOTE 10—The water vapor permeability of mineral fiber insulation is so large that it can not be measured using standard methods. This permeability should be considered when selecting this type of material.

NOTE 11—N/A = Not applicable.

Physical Properties (Note 1) (See Definitions)	Calcium Silicate Pipe and Block	Cellular Glass Pipe and Block	Elastomeric Sheet and Tubular	Expanded Perlite Pipe and Block	Melamine Pipe and Block	Microporous
Applicable ASTM Standard	C533 Type 1	C552	C534/C534M	C610	C1410	C1676
Maximum temperature, °F (C)	1200 (649)	800 (427) (Note 4)	220 – 350 (104 to 175)	1200 (649)	350 (177)	2102 (1150)
Minimum temperature, °F (C)	80 (27)	Minus 450 (-268)	Minus 297 (-183)	80 (27)	Minus 40 (-40)	176 (80)
Density (ASTM C302 and C303) lb/ft^3 (kg/m^3)	15 (240)	6.12 to 8.62 (98 to 138)	3 to 6.5 (48 to 104)	10 to 14 (160 to 224)	0.70 ± 0.10 (11.2 ± 1.6) per ASTM D 3574 Method A	Not Stated
Block compressive strength (minimum) at 5% deformation except where noted (ASTM C165, D3574 Method B) psi (kPa)	100 (688)	60 (415) per ASTM C240 Capped	N/A	70 (483)	80 (36.3) @ 25% / 160 (72.6) @ 65% per D3574	50 – 140 (7.3 – 20.3) @ 10% deformation
Flexural strength (minimum) psi (kPa) (ASTM C446)	50 (344)	41 (283) Block per ASTM C203 Procedure A, Method I or II	Not Stated	45 (310) (Block per C203)	Not Stated	Not Stated
Dimensional change at max. temperature (%) (ASTM C356) (See Table 4)	2 %	Not Stated	7% (per ASTM C534/C534M)	Length 2% Width 2% Thick 10%	Not Stated	Length 2% Width 2% Thick 10%
Surface burning characteristics (ASTM E84) Flame Spread Index / Smoke Developed Index	0/0 (Note 2)	5/0	Not Stated	0/0 (Note 2)	25/50 @ 1 inch (25 mm)	0 / 10
Non combustibility characteristics (ASTM E136)	Pass (Note 2)	Pass	Not Stated	Pass	Not Stated	Not Stated
Water Vapor permeability (ASTM E96/E96M) Perm-inch (g/Pa-s-m) (Desiccant Method)	N/A	0.005 (0.007)	0.10 (1.44 × 10^{-10})	N/A	Not Stated	
Water vapor sorption (by weight) Maximum (%) (ASTM C1104/C1104M)	N/A	N/A	N/A	N/A	25	10 to 5 Based on Type and Grade
Water Absorption (ASTM C209) %				Note 3		
Self-heating (exothermic)	No	No	N/A	No	No	No
Physical properties (Note 1) (See Section 3, Terminology)	Mineral Fiber Block	Mineral Fiber Board	Mineral Fiber Board	Mineral Fiber Blanket	Mineral Fiber Blanket	Mineral Fiber Blanket
Applicable ASTM Standard	C612 Type V	C612 Type IV A&B	C612 Type IA, IB, II and III	C553 Type VII	C553 Type V and VI	C553 Type IV
Maximum temperature, °F (C)	1800 (982)	1200 (649)	450 to 1000 (Note 5)	1200 (649)	1000	850 (454)
Minimum temperature, °F (C))	0 (-18)	0 (-18)	0 (-18)	0 (-18)	0 (-18)	0 (-18)
Density (ASTM C302 and C303) lb/ft^3 (kg/m^3)	Not Stated	Not Stated	Not Stated	12 (192) Max per ASTM C167	10 (160) Max per ASTM C167	8 (128) Max per ASTM C167
Block compressive strength (minimum) at 5% deformation except where noted (ASTM C165) psi (kPa)	1000 PSF (48) 2 inch (50 mm) at 10% deformation	50 PSF (2.4) 2 inch (50 mm) at 10% deformation	25 to 12 PSF (1.2 to 0.6) 2 inch (50 mm) at 10% deformation	N/A	N/A	N/A
Flexural strength (minimum) psi (kPa) (ASTM C446)	Not Stated	Not Stated	Not Stated	Not Stated	Not Stated	Not Stated
Dimensional change at max. temperature (%) (ASTM C356) (See Table 4)	4 %	2 %	2 %	Not Stated	Not Stated	Not Stated

TABLE 1 *Continued*

Physical Properties (Note 1) (See Definitions)	Calcium Silicate Pipe and Block	Cellular Glass Pipe and Block	Elastomeric Sheet and Tubular	Expanded Perlite Pipe and Block	Melamine Pipe and Block	Microporous
Surface burning characteristics (ASTM E84) Flame Index / Smoke Developed Index	Less Than 25/50	Less Than 25/50	Less Than 25/50	Less Than 25/50	Less Than 25/50	Less Than 25/50
Combustion characteristics (ASTM E136)	Fail (Note 2)	Pass (Note 2)	Pass (Note 2)	Pass (Note 2)	Pass (Note 2)	Pass (Note 2)
Water Vapor permeability (ASTM E96/E96M) Perm-inch (g/Pa-s-m) (Desiccant Method)	Note 10	Note 10	Note 10	Note 10	Note 10	Note 10
Water vapor sorption (by weight) Maximum (%) (ASTM C1104/C1104M)	5 %	5 %	5 %	5 %	5 %	5 %
Water Absorption (ASTM C209) %						
Self-heating (exothermic)	No	No (Note 5)	No (Note 5)	No (Note 5)	No (Note 5)	No (Note 5)

Physical Properties (Note 1) (See Definitions)	Mineral Fiber Blanket	Mineral Fiber Metal Mesh Blanket	Miner Fiber Pipe	Mineral Fiber Hydraulic-Setting Insulating and Finishing Cement	Miner Fiber Insulating Cement
Applicable ASTM Standard	C553 Type I thru VII	C592 Type I thru IV	C547 Type I thru V	C449	C195
Maximum temperature, °F (C)	450 (232) 1200 (649)	850 or 1200 (454 or 649)	850 to 1400 (454 to 760)	1200 (649)	1900 (1038)
Minimum Temperature, °F (C))	0 (-18)	0 (-18)	Not Stated	Not Stated	250 (121)
Density (ASTM C302 and C303) lb/ft^3 (kg/m^3)	6 (96) to 12 (192) Max per C167	8 (128) to 12 Max (160 to 192) per C167	2 to 18	Not Stated	Not Stated
Block compressive strength (minimum) at 5% deformation except where noted (ASTM C165) psi (kPa)	N/A	N/A	N/A	Not Stated	Not Stated
Flexural strength (minimum) psi (kPa) (ASTM C446)	Not Stated	Not Stated	Not Stated	Not Stated	Not Stated
Dimensional change at max. temperature (%) (ASTM C356) (See Table 4)	Not Stated	Not Stated	2 % Max	Volume 10% Max per ASTM C 166 Linear Shrinkage 5% per C356	Volume 35% Max per ASTM C 166 Linear Shrinkage 5% per C356
Surface burning characteristics (ASTM E84) Flame Index / Smoke Developed Index	Less Than 25/50	Less Than 25/50	Less Than 25/50	0/0	0/0
Combustion characteristics (ASTM E136)	Pass (Note 2)	Pass (Note 2)	Pass (Note 2)	Not Stated	Pass
Water Vapor permeability (ASTM E96/E96M) Perm-inch (g/Pa-s-m) (Desiccant Method)	Note 10	Note 10	Note 10	N/A	N/A
Water vapor sorption (by weight) Maximum (%) (ASTM C1104/C1104M)	5%	5%	5%	N/A	Not Stated
Water Absorption (ASTM C209) %					
Self-heating (exothermic)	No (Note 5)	No (Note 5)	No (Note 5)	No	No (Note 5)

Physical Properties (Note 1) (See Definitions)	Perpendicular Oriented Mineral Fiber	Rigid Cellular Phenolic Grade 1 Type III	Rigid Cellular Polyisocyanurate Block and Board Type IV thru VI	Polystyrene
Applicable ASTM Standard	C1393	C1126	C591 (Note 9)	C578 Type XIII
Maximum temperature, °F (C)	1000 (538)	257 (125)	300 (149)	165 (73.9)
Minimum Temperature, °F (C)	0 (-18)	Minus 290 (-180) (Note 7)	Minus -297 (-183)	Minus -297 (-183)
Density (ASTM C302 and C303) lb/ft^3 (kg/m^3)	Up to 8 (128) Max per ASTM C303	2 (32) per ASTM D1622/D1622M	2 – 6 (32 – 96) per ASTM D1622/D1622M or C303	1.6 (26) per ASTM D1622/D1622M or C303
Block compressive strength (minimum) at 5% deformation except where noted (ASTM C165) psi (kPa)	25 to 125 (1.2 to 5.7) 2 inch (50 mm) at 10% deformation at 450F (232C)	18 (124) per ASTM D1621	22 – 125 (150 – 862) at 10% deformation	20 (138) at 10% deformation
Flexural strength (minimum) psi (kPa) (ASTM C446)	Not Stated	Not Stated	Not Stated	45 (31) per C203
Dimensional change at max. temperature (%) (ASTM C356) (See Table 4)	Not Stated	2 (per D2126)	4 to 2% per ASTM D2126	2% at 158F / 97% RH per D2126
Surface burning characteristics (ASTM E84) Flame Index / Smoke Developed Index	Less Than 25/50	Less Than 25/50	(Note 2)	(Note 2)
Combustion characteristics (ASTM E136)		N/A	Not Stated	(Note 2)
Water Vapor permeability (ASTM E96/E96M) Perm-inch (g/Pa-s-m) (Desiccant Method)		0.90 (1.3)	4 – 2 (5.8 – 2.9)	1.5 (86) at 1 inch (25)

TABLE 1 *Continued*

Physical Properties (Note 1) (See Definitions)	Perpendicular Oriented Mineral Fiber	Rigid Cellular Phenolic Grade 1 Type III	Rigid Cellular Polyisocyanurate Block and Board Type IV thru VI	Polystyrene
Water vapor sorption (by weight) Maximum (%) (ASTM C1104/C1104M)	5	Not Stated	N/A	N/A
Water Absorption (ASTM C209) %		3 2 hours	2 – 0.8 per ASTM C272/C272M	0.5
Self-heating (exothermic)	No (Note 5)	N/A	N/A	N/A

Physical Properties (Note 1) (See Definitions)	Polyolefin Sheet and Tubular Grade 1	Spray Applied Cellular Polyurethane	Rigid Cellular Polyisocyanurate Faced Board
Applicable ASTM Standard	C1427	C1029	C1289 Type 1 and 2
Maximum temperature, °F (C)	200 (93)	-22 (-30)	200 (93)
Minimum Temperature, °F (C))	Minus 150 (-101)	225 (107)	-40 (-40)
Density (ASTM C302and C303) lb/ft^3 (kg/m^3)	Not Stated	Not Stated	Not Stated
Block compressive strength (minimum) at 5% deformation except where noted (ASTM C165) psi (kPa)	Not Stated	Not Stated	16-25 (110 – 172) per D1621
Flexural strength (minimum) psi (kPa) (ASTM C446)	Not Stated	Not Stated	40 (275) per C203
Dimensional change at max. temperature (%) (ASTM C356) (See Table 4)	7 per C1427	Not Stated	4.0 to 1.5% per D2126
Surface burning characteristics (ASTM E84) Flame Index / Smoke Developed Index	Not Stated	Not Stated	(Note 2)
Combustion characteristics (ASTM E136)	Not Stated	Not Stated	Not Stated
Water Vapor permeability (ASTM E96/E96M) Perm-inch (g/Pa-s-m) (Desiccant Method)	0.05 (7.29 × 10^{-9})	3.0 (4.4)	0.3 – 8.0 (117-458)
Water vapor sorption (by weight) Maximum (%) (ASTM C1104/C1104M)	Not Stated	5	N/A
Water Absorption (ASTM C209) %	0.2	Not Stated	1.0 – 2.0
Self-heating (exothermic)	N/A	N/A	

5.4.1.1 A noncombustible material is defined as a material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat.

5.4.1.2 A material is reported as passing Test Method E136 if at least three of the four test specimens tested meet the individual test specimen criteria detailed below. The three test specimens do not need to meet the same individual test specimen criteria.

(1) If the weight loss of the test specimen is 50 % or less, the material passes the test when the criteria in both *(a)* and *(b)* are met:

(a) The recorded temperatures of the surface and interior thermocouples do not at any time during the test rise more than 54°F (30°C) above the stabilized furnace temperature measured prior to the test.

(b) There is no flaming from the test specimen after the first 30 s.

(2) If the weight loss of the specimen exceeds 50%, the material passes the test when the criteria in both *(a)* and *(b)* below are met:

(a) The recorded temperature of the surface and interior thermocouples do not, at any time during the test, rise above the stabilized furnace temperature measured prior to the test.

(b) No flaming from the test specimen is observed at any time during the test.

5.4.1.3 Test Method E136 includes two different apparatuses and procedures to assess whether a material is noncombustible. One of the alternatives uses the apparatus and procedure of Test Method E2652, but the criteria necessary to pass the test are the same and they are as described in 5.4.1.2.

5.4.1.4 Test Method E136 does not apply to laminated or coated materials and is not suitable or satisfactory for materials that soften, flow, melt, intumesce or otherwise separate from the measuring thermocouple.

5.4.1.5 Test Method E136 can be used to evaluate any insulation material (with the limitations indicated in 5.4.1.4), including composite systems, but in practice it is usually used to evaluate core insulation component materials only. It is rarely used to evaluate facings or adhesives individually, or as a full composite.

5.4.2 In some industrial applications insulation materials are required to be limited combustible materials. When a material is required to be a limited combustible material it must pass the requirements of NFPA 259.

5.4.2.1 A material is considered a limited-combustible material where all the conditions of *(a)* and *(b)* and the conditions of either *(c)* or *(d)* are met.

(a) The material does not comply with the requirements for noncombustible material in accordance with 5.4.1.2.

(b) The material, in the form in which it is used, exhibits a potential heat value not exceeding 3500 Btu/lb. (8141 kJ/kg) where tested in accordance with NFPA 259, Standard Test Method for Potential Heat of Building Materials.

(c) The material has the structural base of a noncombustible material with a surfacing not exceeding a thickness of ⅛ in. (3.2 mm) where the surfacing exhibits a flame spread index not greater than 50 when tested in accordance with Test Method E84.

(d) The material is composed of materials that, in the form and thickness used, neither exhibit a flame spread index greater than 25 nor evidence of continued progressive combustion

when tested in accordance with Test Method E84, and are of such composition that all surfaces that would be exposed by cutting through the material on any plane would neither exhibit a flame spread index greater than 25 nor exhibit evidence of continued progressive combustion when tested in accordance with Test Method E84.

5.4.2.2 Insulation materials that typically comply with this requirement are products that have a noncombustible core but also have a facing and an adhesive.

5.4.3 In some industrial applications insulation materials are required to meet certain surface burning characteristics, usually assessed by means of a flame spread index (FSI) and a smoke developed index (SDI). When a material is required to meet certain values of flame spread index and smoke developed index it usually must be tested in accordance with Test Method E84 (see Table 1).

5.4.3.1 Test Method E84 assesses the comparative surface burning behavior of building materials and is typically applicable to exposed surfaces such as walls and ceilings. The test is conducted with the specimen in the ceiling position with the surface to be evaluated exposed face down to the ignition source. The material, product, or assembly being tested needs to be capable of being mounted in the test position during the test. Thus, the test specimen needs to either be self-supporting by its own structural quality, held in place by added supports along the test surface, or secured from the back side.

5.4.3.2 The purpose of Test Method E84 is to determine the relative burning behavior of the material by observing the flame spread along the specimen. Flame spread and smoke developed index values are reported. However, there is not necessarily a relationship between these two measurements.

5.4.3.3 The use of supporting materials on the underside of the test specimen in Test Method E84 has the ability to lower the flame spread index from those which might be obtained if the specimen could be tested without such support. These test results do not necessarily relate to indices obtained by testing materials without such support.

5.4.3.4 In Test Method E84, testing of materials that melt, drip, or delaminate to such a degree that the continuity of the flame front is destroyed, results in low flame spread indices that do not relate directly to indices obtained by testing materials that remain in place.

5.4.3.5 Several mounting practices have been developed for Test Method E84 and they provide help in the preparation of test specimens and mounting methods.

5.4.4 The tests described in 5.4.1-5.4.3 can all be used to assess the response of materials, products or assemblies to heat and flame under laboratory conditions, but they do not incorporate all the factors required for fire hazard or fire risk assessment of the materials, products or assemblies under actual fire conditions. However, the results of any of these tests can be used as elements of a fire hazard or of a fire risk assessment for a particular end use or application. None of these tests purport to address all of the safety concerns, if any, associated with their use. It is the responsibility of the user of the corresponding standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

5.5 *Compressive Properties:*

5.5.1 Compressive property is the value of the compressive load required to compress or deform a material. Compressive properties are produced by forces that tend to compact the material rather than pull the material's internal structure apart. Excessive/unacceptable deformation is usually considered if permanent or, in other words, if the material does not spring back and recover from the deformation when the load is removed. Many insulation materials exhibit no elasticity or resilience, so compressive "resistance" is defined instead as the load that produces yields, such as 5 %, 10 %, or other specified deformation, per Test Method C165.

5.5.2 The most common compressive forces that insulation should endure in the field are caused by foot traffic, support forces, and differential thermal contraction or expansion between the insulation and insulated steel. Proper design and operating practices will minimize these forces. Proper selection of insulation material will minimize the resulting damage to the insulation.

5.5.2.1 *Foot Traffic*—Many times personnel must gain access to areas for maintenance. The weight of a person can be distributed over an area as small as 2 to 3 in.^{2} (130 to 190 mm^2), depending on the pipe size. For flat surfaces, the force is more evenly distributed over a larger area. If the weight of the person divided by the area of distribution exceeds the compressive strength of the material, damage will occur.

5.5.2.2 *Support Forces*—The weight of the pipe and the content should be transmitted through the insulation to the insulation support rings, bars, or bands.

(1) When insulation is required to support cold insulated piping or equipment insulation should be selected with the necessary compressive strength. An appropriate safety factor that considers static, dynamic, bending moments should be added.

5.5.2.3 *Thermal Strain*—Dimensional changes in the insulation or steel are generally a result of thermal expansion or contraction. When cold insulation is restrained between two nozzles of a steel vessel and the vessel is cooled, the contraction of the vessel and, thus the reduction of the distance between the two nozzles, will result in compression of the insulation. Excessive deformation that is inelastic will yield a material failure. When the length and diameter of a large item increases as the operating temperature increases, insulation may be compressed against the outer jacketing, decreasing the insulation thickness. Test measurements of compressive strength differ from in-service performance for many reasons. Many insulation materials behave inelastically when loaded at elevated temperatures. The load produces a deformation and the material does not "spring back" to the original configuration. The same load applied again will produce a different deformation. A permanent deformation may have previously been induced by packaging, so out-of-the-box testing could give erroneous test results.

5.5.3 The compressive strength of most materials changes with temperature, so the in-service property can be greatly different than the strength measured at room temperature and reported on the data sheet. This may be a result of thermal decomposition of the binder or another organic constituent.

5.5.4 Because of directional cell structure or fiber orientation, some materials, for example C1393 material may exhibit different compressive properties on the axis of loading. Typically, the axis of maximum strength is perpendicular to the axis of minimum strength. Test Method C165 test specimens are prepared so that the direction of loading will compress the insulation thickness. Note that contraction forces, however, may be acting perpendicular to this axis.

5.6 *Corrosivity:*

5.6.1 The corrosion process of metal is very complex and takes many forms depending on the nature of the metal or alloy. A number of factors, such as the presence of inclusions or surface coatings at the interface, the homogeneity of its structure, the nature of the corrosive medium (electrolyte), the incidental environmental factors such as the presence of oxygen or salt-laden air, pollution, temperature, the velocity of the electrolyte movement, and other factors such as stress, oxide scales, deposits on surfaces, galvanic effects between dissimilar metals, and the occasional presence of stray electrical currents from external sources affect the rate and type of corrosion.

5.6.2 Corrosion of piping and equipment under insulation is a serious concern and cost could cost companies millions of dollars every year in repairs, replacement, and lost production. In an effort to minimize this problem, an evaluation needs to be made as to whether the insulation and accessory materials in a particular application will significantly contribute to corrosion. Painting or coating surfaces to be insulated may be the best way to limit corrosion under insulation.

5.6.3 Chlorides or halides contained in insulation may be leached out of the insulation and can exacerbate oxidation corrosion to steel and iron pipes, ducts, and other types of insulated surfaces. In addition, they may exacerbate stress corrosion cracking on austenitic stainless steel. Sources of leachable chlorides and halides in addition to the insulation system are possibly leaking process liquid from within the piping, ambient air containing salts and wash-down water or rain. The most practical way to reduce corrosion is to protect the pipe or equipment with an appropriate coating and seal all openings in the insulation with chloride-free sealant and to use properly designed and installed jacketing and vapor retarder to minimize water entry into the insulation system.

5.6.4 If an evaluation needs to be made as to whether the insulation and accessory materials in a particular application will significantly contribute to stress corrosion cracking of austenitic stainless steel, the following ASTM test methods are currently available and may provide useful information. When applying the results from these tests, consideration must be given to other insulation system factors including the pipe operating temperature, the use of pipe coatings, and the likelihood of water entering the insulation system.

5.6.4.1 Specification C795 for Thermal Insulation for Use in Contact with Austenitic Stainless Steel—This specification covers nonmetallic thermal insulation. In addition to meeting the requirements of this specification, the materials should pass the preproduction test requirements of Test Method C692 for stress corrosion effects on austenitic stainless steel and the confirming quality control and chemical requirements when tested in accordance with the Test Methods C871. Specification C795 puts the results of Test Methods C871 in graphical form to illustrate a range of acceptable chloride plus fluoride concentrations in conjunction with sodium plus silicate concentrations.

5.6.4.2 *Test Method C692 for Evaluating the Influence of Thermal Insulations on External Stress Corrosion Cracking Tendency of Austenitic Stainless Steel*—This test method, often referred to as the preproduction test or 28-day test, is used in determining if a material could contribute to stress corrosion cracking. Testing can also be done with cement, coatings, adhesives, and so forth.

5.6.4.3 *Test Methods C871 for Chemical Analysis of Thermal Insulation Materials for Leachable Chloride, Fluoride, Silicate, and Sodium Ions*—This analysis tells how to test for the leachable chloride, fluoride, ions that accelerate and silicate and sodium ions that inhibit the stress corrosion of stainless steel. When plotted on the graph in Specification C795, it gives some indication that, if the formulation of the materials has not changed and the material passed Test Method C692, it should not cause stress corrosion cracking. Specification C795 requires a pH of water leached from the insulation in accordance with Test Methods C871 to be no greater than 12.5 at 77°F (25°C).

5.6.5 *Control of Corrosion under Thermal Insulation:*

5.6.5.1 Corrosion under insulation (CUI) has been occurring for as long as hot or cold equipment has been insulated for thermal protection, conservation, or process stabilization. The destructive results and nature of the corrosion mechanism are not referenced in the literature until the 1950s. As more problems have been experienced, concern and interest has built around this subject. Many articles and symposia papers have been published since 1983 as interest and activity in CUI have increased. The increased activity was driven largely by many occurrences of severe corrosion under insulation resulting in major equipment outages, production losses, and unexpected maintenance cost in refineries, gas plants, and chemical plants.

5.6.5.2 To avoid these problems, companies have developed their own criteria and approaches to the prevention of CUI. When comparing the various approaches, it is evident that there are many similarities, some differences, some new ideas, and some old ideas that have stood the test of performance.

5.6.5.3 The following ASTM testing is available to assist in determining the effect of insulation material on metal surfaces.

(1) Standard Practice C1617 for Evaluating the Influence of Thermal Insulation on Aqueous Corrosion of Metals. This practice covers procedures for a quantitative accelerated laboratory evaluation of the influence of extraction solutions containing ions leached from thermal insulation on the aqueous corrosion of metals other than stainless steel, Prepared laboratory standard solutions are used as reference solutions and controls, to provide a means of calibration and comparison.

(2) Imbedded test method in ASTM Material Specification C665 for Mineral Fiber Blanket provides a qualitative measure of the corrosiveness of insulation material by comparison to a control.

5.6.5.4 NACE Standard Practice SP0198, The Control of Corrosion under Thermal Insulation and Fireproofing

Materials—A System Approach, incorporates the experience of many companies and shows some solutions to CUI.

5.6.6 *Factors Impacting Corrosion:*

5.6.6.1 Water is the biggest enemy of thermal insulation systems. If moisture migration into the insulation system is prevented, then CUI will be kept to a minimum. In addition to being an excellent electrolyte, without which corrosion could not occur, almost all water contains chloride ions. When water is allowed to enter the insulation system and get to the hot metal surface, the water evaporates and the chloride concentrations after time can reach thousands of parts per million.

5.6.6.2 Per NACE SP0198, stress corrosion cracking of austenitic stainless steel takes place at temperatures above 120°F (50°C). Stress corrosion cracking usually occurs at temperatures just below 350°F (175°C). Processes operating at very high temperatures are subject to stress corrosion cracking during shutdowns.

5.6.6.3 The total insulation system design should take into consideration not only the primary insulation material, but also the possible corrosive contributions of fabricating adhesives, bedding compounds, bore coatings, joint sealants, caulking, facing materials, and so forth.

5.6.6.4 The presence of chloride ions (potentially from salt-laden air) is known to have a very significant effect on the rate of corrosion of steel. This is because not only do the sodium and chloride ions add to the electrical conductivity of the electrolyte, but the chloride ion specifically attacks the protective film on the metal surface. Ingress of other atmospheric species such as nitrates and sulfates are also known to add to the corrosion risk. The ingress of water from external sources containing these species, for example, rainwater, plant spillages, and water used for hosing down equipment may contain sufficient aggressive species to be potentially dangerous for corrosion.

5.6.6.5 Test Method C871 requires that the pH of an insulation material be tested. pH is the negative logarithm of the effective hydrogen-ion concentration or hydrogen-ion activity in gram equivalents per liter in expressing both acidity and alkalinity on a scale whose values run from 0 to 14 with 7 representing neutrality, numbers less than 7 increasing acidity, and numbers greater than 7 increasing alkalinity. These values should be used to help determine the possible effect of the insulation material on corrosion of the metal surface or any coating that may have been used to protect the surface from corrosion.

5.7 *Density*—The weight of a unit volume of insulation is normally expressed as lb/ft^3 (kg/m^3). It is necessary to know the density to calculate loadings and the heating rate when mass is one of the functions. Density should be determined per Test Method C302, Test Method C303, or Test Method D1622/D1622M. These tests methods may require the material to be preconditioned before testing. It is recommended for materials that contain water such as calcium silicate or perlite that the "as-manufactured density" be requested and used when material weight mass is required for design.

5.8 *Dimensional Stability:*

5.8.1 Dimensional stability is the material property that indicates an ability to retain an object's size or shape after aging, cutting, or being subjected to temperature or moisture.

5.8.2 Dimensional changes can affect the ease of installation and may render the material unsuitable for use. Dimensional changes may also produce adverse effects in the installed system, reducing its useful service life.

5.9 *Exothermic Reaction:*

5.9.1 Chemical reaction that release heat are classified as exothermic. Many organic materials used in thermal insulations are exothermic during thermal decomposition when the organic material is exposed to elevated temperatures. If the heat from thermal decomposition is released faster than it can be transferred to the surroundings, the internal temperature of the insulation is elevated. In some instances, the transient internal temperature in insulation can exceed the temperature of the hot surface on which it is installed. In most cases, this transient internal temperature rise should be controlled within safe and tolerable limits. It is necessary to know the thermal stability of the system and each of its components. It is important to know how much and how fast heat is released.

5.9.2 During the design process, designers should anticipate what can occur if the maximum use temperature of the insulation material is exceeded, power is lost, there is a fire exposure, or any other unusual service condition occurs. One control measures include heat-up schedules that raise the operating temperature slowly so that the rate of heat release from any exothermic reaction can be safely dissipated. Careful control of acetylene torches and welding operations around such insulated systems should be instituted.

5.10 *Hygroscopicity*—Hygroscopicity is the tendency of a material to absorb water vapor from the air; this property is especially pertinent for materials whose physical characteristics are appreciably altered by effects of water vapor. The effect depends on the physicochemical nature of the material's surface and increases with increasing relative humidity. See also 5.12.

5.11 *Liquid Water Properties:*

5.11.1 It is important to prevent liquid water from entering the insulating system. The primary method of preventing water from entering the insulating system is the installation and maintenance of a protective weather barrier. A second line of defense can be constructed through the proper design and installation of the additional materials forming the insulating system. The insulation itself can be used in constructing a second line of defense. Insulations offer varying degrees of protection depending on their liquid water transmittance properties. The selection of all materials is dependent on operating conditions and the estimated equipment service life.

5.11.2 The presence of water negatively impacts the insulating system. The impact will vary depending on the operating conditions that establish the thermal gradient and the materials of construction. The following is a summary of the impact of water present within an insulating system for pipes and equipment operating over different temperature ranges.

5.11.2.1 *In temperature ranges of 32°F (0°C) or less*—Water will freeze if allowed to migrate to a point in the insulating system at or below 32°F (0°C). The formation of ice provides an internal destructive force on the insulating system. Ice can quickly destroy the insulating envelope through freeze-thaw cycling caused by ambient air temperature changes.

5.11.2.2 *In temperature ranges of 32 to 212°F (0 to 100°C)*—Water will stay in the liquid phase if allowed to migrate within the insulating system. Water can adversely impact the k-value of those insulations susceptible of retaining water as the k-value of water is well more than an order of magnitude greater than most insulation materials. The presence of water on a metal pipe surface can also lead to corrosion. Corrosion can occur if the combinations of water/metal/oxygen or water/stainless steel/chlorides are present within the insulating system.

5.11.2.3 In temperature ranges equal to or greater than 212°F (100°C)—The total thickness of the insulation material should be evaluated to determine if it is possible that some areas within the material will be at or below 212°F (100°C), thus allowing the insulation to remain wet during operation and decreasing the thermal performance of the material.

5.12 *Liquid Water Absorption:*

5.12.1 Liquid water absorption is the property defined as the amount of water absorbed by a material when in contact with water. Liquid water absorption test methods measure the amount of water absorbed into the insulation under a given set of conditions. Insulation water absorption data gives an indication of how the insulation might resist water given a breach in the weather barrier.

5.12.2 Liquid water absorption properties are measured by several methods that are different for the various types of insulation. All the methods are based on measuring the weight gain of a sample immersed in water following a drain or drip period. Table 2 is a list of ASTM test methods along with the specified submersion period.

5.12.2.1 *Test Methods C209 Procedure*—Condition the specimen until the practical constant weight is obtained at a temperature of 73.4 ± 4°F (23 ±2°C) and a relative humidity of 50 ± 5 %. Measure the thickness of the specimen with reasonable accuracy and calculate the volume from there. Then carefully weigh the specimen and submerge it horizontally under 1 in. (25 mm) of fresh tap water maintained at a temperature of 73.4 ± 4°F (23 ± 2°C). After 2 hours of submersion, place the specimen on end to drain for 10 minutes; at the end of this time, remove the excess surface water by hand with a blotting paper or paper towel and immediately weigh the specimen.

5.12.2.2 *Test Methods C240 Procedure*—Carefully measure the thickness, width, and length to the nearest 0.04 in. (1 mm) of a cellular glass block, preferably 2 by 12 by 18 in. (5 by 30.5 by 460 mm) and calculate the volume and exposed surface area. Weigh the specimen to the nearest 0.004 oz (0.1 g), and then submerge it horizontally under 1 in. (25 mm) of water maintained at 70 ± 5°F (21 ± 3°C). Inert top surface weights are required to keep it submerged. After submerging it for 2 hours, set the specimen on end on a damp cotton bath towel to drain for 10 minutes. After the 10 minutes, remove the excess surface water by hand with a damp sponge for 1 minute on the large face and 1 minute on the four sides. Wring out the sponge before and once in between for each face and pass it at least two times on each surface.

5.12.2.3 *Test Method C272/C272M Procedure*—Completely immerse the specimens, resting on edge, in a container of distilled water maintained at a temperature of 73 ± 5.4°F (23 ± 3°C). At the end of 24 hours, remove the specimens from the water one at a time, wipe off all surface water with a dry cloth, and weigh immediately.

5.12.2.4 *Test Method D2842 Procedure*—After cutting specimens, condition them in a forced-air circulating oven for 24 hours or more at 122 + 5°F (50 ± 3°C). Place the underwater weighing jig in an immersion tank. Immerse the specimens with a suitable weighted rack in an open top immersion tank filled with freshly distilled water at 73.4 ± 3.6°F (23 ± 2°C). Adjust the water level to maintain a 2-in. (50-mm) head of water over the top of the specimens with 6- by 6-in. (150 by 150 mm) faces in the horizontal position. Remove obvious air bubbles clinging to the specimen with a soft bristle brush. Cover the entire surface of the water with low-permeance plastic film. Leave specimens immersed for 96 h while maintaining a 2-in. (50 mm) head of water at 73.4 ± 3.6°F (23 ± 2°C). Attach the underwater weighing jig to balance with a wire sling such that the top horizontal surface of the jig is 2 in. (50 mm) below the surface of the water. Be sure that the submerged jig is free of trapped air bubbles. Weigh the empty submerged jig to the nearest 0.004 oz (0.1 g). Insert the test specimen into the submerged underwater weighing jig without removing the specimen from the water. Weigh to the nearest 0.004 oz (0.1 g). Do not remove any specimens from the water until all have been weighed, as removing specimens reduces the 2-in. (50 mm) head.

5.12.2.5 *Specification C610 Procedure*—This test procedure evaluates the water absorptivity of the insulation material after being exposed to an elevated temperature. Two specimens are required for this test procedure.

(1) One specimen is placed in an electric oven and the second is used as a control sample. The oven is operated at 600°F (316°C) for a minimum of 24 hours. The heat treated specimen is removed and along with the control specimen placed in a controlled environment of 73 ± 1.8°F (23 ± 1°C) and 50 ± 5 % relative humidity. After the specimens have cooled for at least 12 hours in the control environment, weigh each of the specimens to the nearest 0.004 oz (0.1 g).

TABLE 2 ASTM Test Methods that Measure Liquid Water Absorption Properties

ASTM Test Method	Submersion Period, hours
C209 Test Methods for Cellulosic Fiber Insulating Board	2
C240 Test Methods of Testing Cellular Glass Insulation Block	2
C272/C272M Test Method for Water Absorption of Core Materials for Structural Sandwich Constructions	24
C610 Specification for Molded Expanded Perlite Block and Pipe Thermal Insulation	48
C1511Test Method for Determining the Water Retention (Repellency) Characteristics of Fibrous Glass Insulation (Aircraft Type)	15 min
D2842 Test Method for Water Absorption of Rigid Cellular Plastics	96

(2) Completely immerse each specimen so that a head of 1 in. (25 mm) of distilled water at ambient temperature is maintained for a minimum of 48 hours. Withdraw each specimen and quickly wipe off excess surface moisture with a damp cloth. Immediately weigh each specimen to the nearest 0.004 oz (0.1 g).

(3) Calculate the percent of water absorption by weight, using the weights obtained after heat soaking as the dry weight. The calculation should be as follows:

$$\text{Weight absorption} = 100 \times (W_{AI} - W_{AHS})/W_{AHS} \quad (2)$$

where:

W_{AI} = after immersion specimen weight, and
W_{AHS} = after heat soak specimen weight.

5.13 *Maximum/Minimum Temperatures for Continuous Operation:*

5.13.1 When choosing an insulation material for any given service, one major concern is system-operating temperature(s) (minimum/maximum) and the proper insulation material(s) designed for use within those operating parameters. Insulation materials' intended operating temperature ranges for insulation materials are normally specified by the insulation material manufacturers.

5.13.2 Insulation manufacturers will normally publish a recommended temperature range based on thermal properties at the rate per the recommendations of the manufacturer or with little regard to other physical properties. When selecting an insulation material, this recommended range should be the first consideration. Next, test results obtained from Test Method C411 or Practice C447 should be considered.

5.13.2.1 Test Method C411 stipulates that the insulation material be applied on a test plate or pipe while at ambient temperature. The temperature is then brought up at a rate per the recommendations of the manufacturer or the rate of the intended service. After the product has been heated to the maximum temperature and held for approximately 96 h, a report is written to specify the kind of insulation material tested, number of segments tested, temperature of test, number and extent of cracks, warpage, cracking, delamination, sagging, decrease in thickness, or any other visible changes. Also, this report should define any evidence of flaming, glowing, smoldering, smoking, and so forth.

5.13.2.2 Practice C447 requires that the pipe or plate be heated to the maximum temperature before the material is applied unless a specific heat up temperature limit is specified by the manufacturer. The product is maintained at this maximum temperature until equilibrium is reached and then held until all the major changes occur within the product, usually within 96 hours. A rapid heat up within the insulation may cause an undesirable exothermic change resulting with ultimate/irreversible damage. After exposure on the hot surface for 96 hours the product is then cooled and, in addition to visual examination and report made per Test Method C411, material properties are tested and reported, that is, compression, thermal conductivity, flexural strength, and so forth in addition to any damage resulting from excessive exotherming. Note that the properties and values obtained after testing at maximum temperature may eliminate that insulation material from consideration. Determination of material acceptability should be made by the specifier after review of the test results.

5.13.3 There is no existing ASTM standard for testing, specifying, or reporting results for minimum operating temperatures for cold-service pipe insulation materials.

5.13.4 When the temperature of the system to be insulated is cyclic in nature, operates at temperatures below ambient, and then regenerates at temperatures well above ambient or operates with combinations of maximum and minimum temperatures, it may be necessary for the specifier to look at the combinations of maximum and minimum tests results plus all associated properties to determine the need for one type of material for an inner layer and another type for the outer layer(s).

5.14 *Resilience*—Resilience is the ability of a material to recover dimensionally upon release from stress. When insulation is used to take up dimensional change, such as in an expansion (contraction) joint, a low-compressive strength may be needed. The percentage of recovery to original size upon the relief of stress is important.

5.15 *Service Life:*

5.15.1 One of the major concerns of a designer is to provide the owner with some assurances that insulated systems will perform as intended for an extended period of time There is no accepted handbook containing recipes for establishing how to estimate the duration or "service life" periods for insulated systems in the industrial market segments. Even the definition of the term extended period of time can range from several months to as much as 20 or more years. There are too many extremes and too many variables to make specific comments applicable to every system. Service temperatures range from cryogenics up to 2300°F (1260°C), and ambient conditions range from mild indoor conditions to severe outdoor exposures of temperatures, humidity, and weather. Anecdotal information tells us that design conditions in Houston for outdoor systems are not the same for Philadelphia, Chicago, Los Alamos, or Fairbanks. Anecdotal information tells us that what should be done for cold surfaces is different from what should be done for hot surfaces. Anecdotal information tells us that what should be done for ducts, tanks, and pipes in residential buildings is simple because the major fluids in the insulated systems are usually air and water at temperatures usually below 250°F (121.1°C). The same holds true for commercial construction in which air and water are the principal fluids being contained. In the industrial sector, water is handled as a liquid, ice, saturated steam, and superheated steam. Other gasses, liquids, solids, and chemicals that may be corrosive, unstable, combustible, or toxic also should be handled in the industrial sector.

5.15.2 Long service life denotes that the designed thermal performance is maintained to some high percentage of the original design. Long service life of insulated systems requires the engineer or designer to have good knowledge of the materials in the pipes, tanks, vessels, equipment, towers, and heat exchangers. It demands the proper selection of construction materials to contain these materials safely under anticipated conditions of weather, wind, fire, shock, vibration, and seismic exposure. It needs the proper selection of the appropriate insulation materials to meet the specific thermal design requirements of the system in service and over a long period of time. It relies on the proper design details and proper installation to reduce or eliminate the deleterious effects of expansion or contraction and excessive heat flows through parallel paths. It demands the proper selection of surfacing treatments to protect the insulated system from mechanical abuse or weather-related damage in normal service. It depends on the proper selection of maintenance procedures to inspect and repair the system regularly and quickly. All of these things should be accommodated within the cost constraints superimposed by the owner.

5.15.3 Long-term service life demands that the insulated system be well designed, well built, operate as designed, and well maintained. Weaknesses in any area of design, installation, operation, or maintenance will shorten the service life of an insulated system.

5.16 *Shrinkage:*

5.16.1 Shrinkage, otherwise referred to as linear shrinkage, is the material property that indicates the dimensional or volumetric changes that occur when exposed to cryogenic or elevated temperatures. These changes are irreversible. Linear shrinkage is determined in accordance with the test method specified in the material standard. Linear shrinkage is established after the material has been subjected to a soaking heat for a period of 24 hours, usually at the maximum temperature limit of the material.

5.16.2 The linear shrinkage under soaking heat listed within various ASTM material specifications is a maximum rate. However, the rate of shrinkage is nonlinear across the material-use temperature range. That is to say, a material may experience very little or no shrinkage at low or moderate temperatures.

5.16.3 Most insulating materials will begin to shrink at some definite temperature. Usually the amount of shrinkage increases as the exposure temperature increases. Eventually a temperature will be reached at which the shrinkage becomes excessive, which is an indication that the exposed temperature has exceeded the materials maximum temperature limit.

5.16.4 When an insulating material is applied to a hot surface, the shrinkage will be greatest on the hot face. The differential shrinkage that results between the hot and cold surfaces often introduces strains and may cause the insulation to warp. High shrinkage can produce excessive warpage and induce cracking, both of which are undesirable. Sufficient warpage can be disruptive to insulation securement systems.

5.16.5 High shrinkage may also open gaps at the insulation joints to an excessive extent, rendering the installed system less thermally efficient and possibly more hazardous. To predict the limit of permissible shrinkage in service, the degree of linear shrinkage to be tolerated by specimens of an insulating material when subjected to soaking heat should be determined from experience.

5.16.6 One method of controlling warpage and stress-induced cracks is to install the insulation system in multiple layers. The layering reduces the differential shrinkage between the hot and cold surfaces of the individual layers. By offsetting the insulation joints between layers, any gaps that open at joints in an individual layer result in less significant losses in thermal efficiency.

5.16.7 Linear shrinkage may also need to be considered when designing insulation expansion joints in high-temperature insulation systems. However, it will be necessary to obtain the linear shrinkage rates at different temperatures from the material manufacturer. These rates should be obtained from each manufacturer of a generic material type, since each may have different rates.

5.17 *Specific Heat/Specific Entropy*—Specific heat is the quantity of heat required to change the temperature of a unit mass of a substance one degree. It is essential to know this property in selection of materials for intermittent or transient operations. The unit of measurement in inch pounds is one Btu per pound per degree Fahrenheit Btu/lb°F (Joules per kilogram degree Celsius or Kelvin (J/kg.K). See Test Method C351 for additional information.

5.18 *Thermal Diffusivity*—This property may be important in some cases. In cyclic services rapid dissipation of temperature may be desired or a high rate of thermal transference is important. Substances with high thermal diffusivity rapidly adjust their temperature to that of their surroundings, because they conduct heat quickly in comparison to their thermal 'bulk'.

5.19 *Thermal Resistance*—Thermal resistance {R-value} is usually determined at 75°F (23.48°C) mean temperature. It is the reciprocal of thermal transmission transmittance {U-value}. The R-value is normally used for nonindustrial insulation applications such as insulation in building envelopes.

5.20 *Thermal Shock Resistance*—This is a property of a material that indicates its ability to be subjected to rapid temperature changes without physical failure. This property is important when an insulation material is installed on cyclic, fast heat ups or fire protection systems.

5.21 *Vibration Resistance:*

5.21.1 This is a property of a material that indicates its ability to resist physical damage, without wearing away, settling, or dusting off. Almost any insulation used in an industrial application will be subjected to some vibration, such as compressor vibration, fan pulsations, or vibrations caused by the fluids or gases passing through the line or vessels.

5.21.2 Fibrous materials tend to resist vibration. ASTM testing such as Specification C1139 is applicable to only some fibrous materials with densities less than or equal to 3 lb/ft^3 (48 kg/m^3) and is performed at ambient temperatures.

5.22 *Water Vapor Permeability:*

5.22.1 Water vapor permeability is defined in Test Methods E96/E96M as the time rate of water vapor transmission through unit area of flat material of unit thickness induced by unit vapor pressure differential between the two specific surfaces under specified temperature and humidity conditions. The permeability of a material is expressed in terms of the weight of the water vapor transmitted through a unit thickness of the material, divided by the vapor pressure differential, the time, and the area of the material. Hence, the lower the permeability, the more resistance it is to the diffusion of moisture vapor through a given thickness of it. The units of permeability are g/(Pa·s·m) or Perm inch. A Perm is 1 grain/(ft^2·h·in. HG).

5.22.2 Water vapor permeance is the time rate of water vapor transmission through unit area of flat material or construction induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions. The units of permeance are g/(Pa·s·m^2) or Perm. Note that permeance is not a material property but a performance evaluation of the test specimen. It is the ratio of material permeability to sample thickness; hence, it is equally dependent on both thickness and permeability.

5.22.3 If you wish to calculate the permeance of a thickness other than that at which the coating was tested (Test Methods E96/E96M, Procedure B), you simply multiply the permeance by the dry film thickness that was tested. This gives you the permeability of the product. You then take this figure (perm-inches) and divide by the thickness you wish to evaluate. This will give you the approximate permanence (in perm) at that thickness.

5.22.4 Water vapor transmission is the quantity of water vapor transmitted through a unit area per unit time under specified conditions of humidity, temperature, and thickness. The units for WVT are g/(h·m^2) or grains/(h·ft^2).

5.22.5 Test Methods E96/E96M describes two basic methods the desiccant method and the water method, for the measurement of permeance, and two variations including service conditions with one side wetted and service conditions with low humidity on one side and high humidity on the other. Agreement should not be expected between results obtained by different methods. While WVT results from using conditions that most closely approximate field exposure, actual field exposure are preferred, most WVT data is provided at conditions of 73°F on both sides of the sample and humidities of 0 and 50 % or 50 and 100 % on either side of the sample. In the desiccant method, one face of the sample is sealed to a test dish containing a desiccant. The sample is exposed to a set of controlled conditions, and then periodically weighed to determine the rate of vapor movement through the sample into the desiccant. In the water method, one face of the sample is sealed to a dish containing water. Again, the sample is exposed to a controlled atmosphere, and then periodically weighed to determine the rate of vapor movement from the dish, through the sample, into the controlled atmosphere. A set of six standard conditions for the test are listed by ASTM. These are listed in Appendix X1 Test Methods E96/E96M. Be aware that no two different test conditions are likely to yield the same test results on the same material. Therefore, to make accurate comparisons, the materials being compared should be tested using identical conditions.

5.22.6 Water vapor can penetrate all but a few materials. In insulated systems that operate below ambient or in the above ambient systems that are periodically shut down, the vapor drive is often into the system, that is, the vapor pressure outside the insulation is higher than the vapor pressure next to the pipe, tank, vessel, and so forth. This pressure difference causes water vapor to migrate into the insulation and eventually reach a point where condensation and, if conditions are right, ice formation occurs. Once this condensation begins, the thermal insulating properties of the insulation assembly begin to degrade. Add to this the fact that the moisture present can lead to other problems such as corrosion, mold and mildew growth, and sweating or dripping. Most often, in addition to choosing an insulation with low permeability for below-ambient service, vapor-retardant jackets, coatings, and/or sealants will be needed as part of the system. The relative permeability of these accessory materials should be taken into account when designing the system.

5.23 *Wicking:*

5.23.1 Wicking is the ability of a porous material to elevate or translate liquid water via capillary action. Nonporous materials and some of those with a non-hydrophobic characteristic or treatment do not wick. The wicking test method measures the insulation's capillary action given a set of conditions. Insulation wicking data indicates how the insulation will or will not transport water given a breach in the weather barrier.

5.23.2 Wicking is measured in accordance to Test Method C1559. In this test, a strip of the material is suspended mostly in air, with the lowest portion under water. The height to which water rises over a certain period of time is the amount of wicking.

6. Design Considerations

6.1 *System Design Consideration*—Insulation system design requires fulfilling process, thermal, and mechanical requirements. Along with careful selection of insulation materials and weatherproofing, the need for expansion/contraction joints, vapor stops (cold service), and proper flashings and sealing should be addressed in the system design. The specific purpose of the insulation, extent of insulation, limits of insulation, and items to be insulated are all part of decision making under insulation system design.

6.1.1 *General:*

6.1.1.1 Preplanning for thermal insulation should be carried out when laying out piping and equipment during the early phase of the design of new construction to allow for clearance of insulation around pipes, flanges, and equipment. Insulation adds weight to piping; therefore, resting-type and spring-hanger-type pipe supports should be designed to carry the extra load.

6.1.1.2 While the initial cost of the insulation system is important, other factors, such as meeting technical requirements, availability, and desired length of service, should also be considered.

6.1.1.3 Energy conservation is often the primary reason for specifying insulation, but there may be other reasons. For example:

(1) Process control and stabilization by maintaining a fluid temperature within specific limits or to ensure that a fluid retains specific physical properties at the point of delivery,

(2) Protection of personnel from hot and cold surface temperatures,

(3) Minimization of temperature gradients or prevention of sudden temperature changes as a result of weather changes,

(4) Maintenance of the internal temperature of a fluid above a specified minimum temperature to avoid corrosive attack from condensing acids,

(5) Prevention or minimization of surface condensation on systems operating at below ambient,

(6) Limitation or control of heat gain to the system operating at below ambient temperatures,

(7) Protection against freezing or hydrate formation,

(8) Noise control, and

(9) Fire protection.

6.1.2 *Piping and Equipment Design*—Piping and equipment layout should provide adequate clearance for insulation so that the weather or vapor retarders will be continuous to prevent rain or moisture from entering into the insulated system. The equipment designer should consider insulation thickness when designing attachments to vessels such as nozzles, ladders, and platforms where sufficient clearance is needed to provide for bolt removal without damaging the equipment's insulation. Pipes should rest on pipe supports in the pipe racks. When pipes are supported on structural steel, the pipe should be elevated enough to allow for the full thickness of the insulation to clear the steel in above-ambient applications (hot service). Pipes in below-ambient applications (cold service) should be supported on load bearing design insulated supports with a continuous vapor retarder and with specified protective / weather barrier covering. On trunnions, supports or other protrusions through cold insulation the insulation shall be carried onto the protrusion a sufficient distance to limit heat loss, heat gain or prevent condensation. In below ambient service protrusions shall also be vapor sealed. In both applications, support assemblies should move with the pipe to prevent the opening of the insulation joints.

6.1.3 *Insulation of Valves and Flanges:*

6.1.3.1 Unless required to maintain critical temperature, minimize heat gain, condensation control, freeze protection, or personnel protection, valves and flanges should not be insulated for economic reasons. A leak detection device may be installed over insulated flanged connections in hot service to allow for testing of fugitive emissions to comply with 40 CFR 60, Appendix A, Method 21. It is not advisable to install such devices over flanged connections in cold service. Valves in cryogenic service should have extended bonnets insulated up to half of their column height to keep the packing gland close to ambient temperature.

6.1.3.2 Maintenance requirements may dictate whether the insulation system is permanent or removable.

6.1.3.3 Insulation at flanges should allow enough clearance for bolt or stud removal when possible on both sides of the joint.

6.1.4 Design guidelines for various insulation services are shown in Table 3.

6.2 *General Design Considerations:*

6.2.1 *Geographical Location:*

6.2.1.1 Geographical design considerations depend on plant location. Plants located in hot and humid climates will have different parameters than plants located in a dry cooler climate. The National Weather Bureau, ASHRAE, U.S. Meteorological services, Site Data or similar service provides local weather data which can be used in determining the minimum, maximum and average daily temperatures, wind, humidity and rainfall.

6.2.1.2 Review of the following parameters should give the necessary design data:

(1) Wind,

(2) Snowfall,

(3) Extreme temperatures,

(4) Relative humidity,

(5) Rainfall,

(6) Water table, and

(7) Seismic readings.

6.2.2 *Environmental Corrosivity*—The location of a plant near an industrial complex where potentially corrosive chemicals are present or near coastal areas can affect the selection of insulation and weatherproofing materials as well as application procedures. Insulated equipment located near a cooling tower or ash-handling equipment will be exposed to a more corrosive environment than will the other plant equipment. Corrosives mixed with moisture can promote corrosion of substrate steel. Equipment located in such corrosive areas may require a heavy-duty protective coating.

6.2.3 *Design Temperatures*—The ambient temperatures selected for insulation design in hot service, cold service, freeze protection, and steam or electric tracing service should be agreed upon between the owner and the designer. The temperature selected will depend on the design scenario. For scenarios requiring a maximum or minimum jacket surface temperature such as personnel protection in hot service or condensate control an extreme of ambient temperature should be selected. This could be a 95th, 99th or even 99.4th percentile of hot or cold ambient temperature. Likewise for freeze protection and steam or electric tracing an extreme ambient temperature must be selected and the prevailing wind condition must also be considered. For insulation design scenarios targeted at energy savings including "economic thickness", it is appropriate to use the year-round average temperature. This is the case for both cold and hot temperatures. When insulating primarily for process control, the selection of ambient design temperature will be based on yearly extremes of temperature with the degree of extreme (for example 95th, 99th, or 99.4th percentile) selected depending on the mission criticalness of the insulation system and the consequences to the process and to safety of exceeding the desired process temperature for short periods of time.

6.2.4 *Design Wind Velocity*—Wind velocity has a direct impact on mechanical and thermal design of insulation. It is essential that the wind velocity design values are established early in the project. Wind velocity for calculation of heat losses is different from the wind velocity for mechanical design. Wind velocity should not be considered when designing insulation for pipe and equipment that are shielded by other major plant equipment or closed structures or for items located indoors.

6.2.4.1 *Effects of Wind on Insulation Thicknesses:*

(1) Wind has a huge effect on the jacketing surface temperature of an insulated item but has only a small effect on the heat flux. Wind significantly lowers jacket surface temperature

TABLE 3 Example of General Design Guidelines for Various Insulation Services (These Should be Verified on Each Project Based on Project Requirements)

Service	
Process Control or Product Stabilization (Hot Service)	Insulate when normal operating temperature exceeds ambient and the prevention of the loss of heat is critical to the operation or control of the equipment or piping, or to the quality of the process steam. PIPING 1. Insulate process lines in which the prevention of heat loss is critical to the system. 2. Steam piping requires insulation. 3. Valves, valve bonnets, and flanges should be insulated up to a temperature of 500°F (260°C). Above 500°F (260°C) these items are normally not insulated so as to prevent possible leaks at bolted connections caused by differential expansion between the pipe and bolts. EQUIPMENT 1. Insulate process equipment, heat transfer equipment and steam turbines. 2. Equipment flanges and manholes are to be insulated. 3. Exchanger channel sections and body flanges require insulation. 4. Insulate equipment in steam service and/or if the prevention of heat loss is critical to the system. 5. Normally pumps under 400°F are not to be insulated, unless the prevention of heat loss is critical to the system. Personnel protection may be required when the fluid temperature is 140 to 400°F (60 to 204.4°C). 6. Fans, compressors, and blowers are not to be insulated unless the prevention of heat loss is critical to the system. 7. External insulation *should not* be used on internally insulated equipment. 8. Insulate expansion joints and similar types of mechanical equipment unless loss of heat is critical to the system.
Energy Conservation (Hot Service, excluding Sound Control) PIPING	Insulate when normal operating temperature exceeds 140°F (60°C), unless loss of heat is desirable. 1. Insulate piping to limit the loss of heat. 2. Valves, valves bonnets, and flanges *may not* be insulated except in steam service, traced piping systems or as otherwise specified by the Owner EQUIPMENT 1. Equipment flanges and manholes are to be insulated. 2. Exchanger channel section and body flange *are not* insulated, unless required for personnel protection. 3. Pumps under 400°F (204.4°C) *are not* insulated. Personnel protection may be required when the fluid temperature is 140 to 400°F (60 to 204.4°C). 4. Fans, compressors, and blowers *are not* insulated. 5. External insulation *should not* be used on internally insulated piping or equipment. 6. Expansion and rotation joints and similar types of mechanical equipment *are not* insulated.
Steam or Electric Heat Tracing	The operating temperature of the product or tracer temperature required to be maintained should be considered when determining the thickness and material of insulation. Thermal requirements of the insulation are the same as for process control or cold conservation depending on the temperature.
Sound Control (Above Ambient)	Insulation is required for sound attenuation.
Fire Protection	Insulation is used to limit heat buildup in piping or equipment during a fire. Credit may be taken in relief sizing if proper insulation and weatherproofing are used. (API 521 may be used as a guide for this requirement).
Personnel Protection (PP) (Hot Service)	Insulation or shields are to be provided where the normal operating temperature exceeds 140°F (60°C), but only those portions of piping or equipment to which the following apply: 1. The hot surface is in an area in which personnel are regularly performing duties, other than maintenance, during the plant operation. 2. The hot surface is within 7 ft (2 m) above or within 2 ft (0.6 m) or both beyond accessways, ladders, platforms, floors, grade, or paving. Shields should be ventilated metal guards or screens; they should be used rather than insulation for temperatures up to 300°F (148.8°C) and for the following conditions: 1. PP applications where heat loss is desired. 2. PP applications on internally insulated piping or equipment. 3. When specified on the piping and instrument diagrams. (Note: ASTM C1055 may be used as a guide for determining the temperature at which personnel protection should be used.)
Cold Conservation or Control of Heat Gain	Insulate when normal operating temperature is below ambient and it is desirable to minimize heat gain. Uninsulated items could have surface condensation with dripping which could cause an unsafe condition (see Anti-sweat).
Anti-sweat or Prevention of Surface Condensation	Insulate when the normal operating temperature is below 80°F (26.6°C) to prevent, condensation, sweating, or ice formation which could cause an unsafe condition, equipment damage, corrosion, or lead to wet poorly performing insulation. In the rare case where heat gain into the system is desirable a decision must be made whether sweating, condensation and ice formation are acceptable.
Sound Control (Below Ambient Temperatures)	Insulation is required for sound attenuation.
Personnel Protection (Cold Services)	Insulation or shields are to be provided where the normal operating temperature is below 0°F (-18°C), but only those portions of piping or equipment to which the following apply: 1. The cold surface is in an area where personnel are regularly performing duties, other than maintenance, during plant operation. 2. The cold surface is within 7 ft (2 m) above or within 2 ft (0.6 m) or both beyond accessways, ladders, platforms, floors, grade, or paving. Shields should be ventilated metal guards or screens; they should be used rather than insulation for the following conditions: 1. PP applications where heat gain is desired. 2. PP applications on internally insulated piping or equipment. 3. When specified on the piping and instrument diagrams.

in above-ambient application and raises jacket surface temperature in below-ambient application. This has dramatic impact on the insulation thickness necessary to control jacket surface temperature. While wind does increase heat loss or gain, this effect is minor and the impact on insulation thickness necessary to achieve a heat flux limit is small. Wind also has an effect on the amount of time it takes for the content of a pipe or equipment to freeze but since this is a heat flux phenomenon, this impact is fairly small.

(2) In below-ambient applications, wind raises the jacketing temperature of an insulation item thus requiring less insulation thickness to keep this temperature above the dew point and decreasing the likelihood of condensation. In above-ambient application, wind lowers the jacketing temperature of an insulated item thus requiring less insulation thickness to keep this temperature below the personnel protection limit. Therefore, it is essential tot establish the design wind velocity before any surface temperature calculations are considered. If the only way the desired surface temperature is achieved is by assuming the presence of wind, consideration must be given to the scenario where the wind is not blowing. In this case, the jacket surface temperature will reach more of an extreme. In a hot personnel protection situation, this might lead to a safety issue. In cold control situation, this might lead to increase risk of condensation especially if the low wind is coincident with a period of high humidity.

(3) When selecting the design wind velocity the impact of extremes of velocity should be considered. It may be necessary to design to an extreme of velocity (either very high or zero) in order to achieve the desired performance of the insulation system.

6.2.4.2 *Effects of Wind on Metal Jacketing and Securement*—High wind can damage insulation and jacketing unless the insulation designer designs securement to withstand the wind load. On tall towers and large storage tanks, insulation is vulnerable to wind damage because of lifting (negative) forces generated by high wind on the trailing wind side. The wind load design data for various geographical areas can be found in the appropriate ASME standard. It may be necessary to choose an insulation of higher compressive resistance to support thin-gauge jacketing.

6.2.5 *Relative Humidity*—The higher the relative humidity, the closer the dew point temperature is to the ambient temperature. The insulation thickness required to prevent condensation (maintain the insulation jacket above the dew point) will be thicker for high-humid areas. In outdoor application or in other non-climate controlled environments, it is impossible to prevent condensation 100 % or the time because of rain or periods when the relative humidity is very high (such as early morning) or both. In some hot and humid climates, relative humidity of near 100 % is common on many spring and summer mornings, leading to heavy dew and even morning fog. In these environments, condensation on the jacketing of the insulation system is almost certain and must be considered in the design of the insulation system and the facility. Various sources of weather data such as the National Weather Bureau data for nearest to the plant site and any influencing factors at equipment or pipe locations should be investigated before selecting the relative humidity design value for a given project. In applications in climate controlled environments, condensation on the jacketing can be prevented by selecting a design relative humidity greater than that which will ever be encountered in the climate controlled area. In climate controlled environments there is a particular risk of condensation on the insulation system jacketing if the system is operated during periods when the climate control is either malfunctioning or before is has been commissioned. Shelf life of insulation materials and hydraulic setting insulating cements can be affected by high humidity. These materials require special protection during transportation and jobsite storage. High atmospheric relative humidity can cause surface condensation and accelerate corrosion of unprotected metal pipe and jacketing. Non-wicking types and close-cell insulation materials are minimally affected by high humidity, and they tend to retain their insulation value in these conditions. The use of low permeance vapor retarders, with appropriate attention to the sealing of joints with low vapor permeance tapes and / or mastics, minimizes the migration of moisture into the insulation system.

6.2.6 *Safety:*

6.2.6.1 The design of insulation for pipe and equipment handling hazardous chemicals such as flammable or toxic materials requires special consideration in the selection of insulation materials, weatherproofing materials, and application methods.

6.2.6.2 Insulation systems required to reduce fire loading will need insulation materials and accessories rated to withstand a hydrocarbon fire for a specific duration. Weatherproofing materials in this case will be stainless steel or coated steel jacketing since aluminum jacketing and mastic weatherproofing cannot withstand the intensity of the fire and still be functional.

6.2.6.3 Insulation materials that can absorb liquids and cause the flash point of the liquid to be reduced should not be used in such service. Nonabsorbent-type insulation materials should be used in these services.

NOTE 1—Hydrophobic insulation materials may or may not be nonabsorbent to the liquid in question. Until determined by tests to be otherwise, hydrophobic materials should be considered absorbent with a liquid other than water.

6.2.6.4 Nonabsorbent-type insulation materials may also be required for toxic services in which trapping of a toxic substance in the insulation can pose a health hazard.

NOTE 2—Hydrophobic insulation materials may or may not be nonabsorbent to the toxic substance in question. Until determined by tests to be otherwise, hydrophobic materials should be considered absorbent with a toxic substance.

6.3 *Physical Design Considerations:*

6.3.1 *Rigid Versus Compressible*—Rigid insulation with a high compressive strength is resistant to deformation when subjected to foot traffic or excessive tightening of securement (bands). Compressible insulation does not offer the same resistance to such loads. Areas that experience loads or repetitive personnel access/use will require a firmer system than inaccessible areas. It is recommended that insulation with a compressive strength greater than about 30 psi at 5 % (206 kPa) deformation, as determined per C165, be used for areas subjected to foot traffic and / or other external loads that might otherwise damage a compressible insulation material. Piping used as ladders/walkways, riggings hung from pipes, and horizontal surfaces subject to vibration/loads are examples, whereas compressible insulation is required for filling voids and closing gaps in insulation that allows expansion, contraction, or movement of rigid insulation.

6.3.2 *Mechanical Abuse Potential*—Mechanical abuse should be considered on a case-by-case basis. Insulated items located in high-traffic areas should have a structure such as a platform or similar protection to avoid stepping directly on insulation. Insulation termination at bolted connections should be cut back far enough to allow bolt removal without damaging the sealed ends of termination. Insulation on valve handles should be cut back to allow access to packing glands. At the same time, if valve handles are too close to other insulated items, the insulation should be cut back and sealed to allow free movement of the valve handle. Items requiring frequent maintenance should have removable insulation. An inspection window cut into the insulation should have inspection plugs.

6.3.3 *Clearances between Piping*—Space limitations may require pipe "bundling" to accommodate insulation. This is usually accomplished with a combination of pipe insulation and insulation boards. Care should be taken not to insulate pipe together when they run at significantly different temperatures as it may affect the process. The best choice may be to relocate the lines or insulate them with less insulation but still maintain a continuous vapor and weather seal. Insulation on lines should never be grouped with interfering structural steel.

6.4 *Chemical Design Considerations:*

6.4.1 *Hot Oils/Heat Transfer Fluids*—See 5.2 and 6.2.6.3.

6.5 *Insulation Design Thickness:*

6.5.1 *Insulation Thickness Hot Surfaces:*

6.5.1.1 The three factors that influence the selection of hot insulation thicknesses are thermal energy loss, economics, and personnel protection from surface temperatures. Calculations for the determination of insulation thickness using maximum allowable energy loss and/or economic insulation thickness criteria do not consider insulated surface temperature as an input. This means that three tables of insulation thickness(es) may be necessary: one for maximum allowable energy loss, one for economic thickness, and one for personnel protection.

(1) Calculations for Maximum Allowable Energy Loss—These calculations are both project and system specific. To maintain the process in a particular system, a fluid may require a minimum allowable temperature drop from one point to another, over the length of a particular pipe. To determine the minimum required insulation thickness, the designer needs to know the process temperature, pipe size and orientation (or, if equipment, its orientation), lowest expected ambient temperature, highest expected wind speed, insulation jacketing emittance, and at least three mean temperature thermal conductivity values for the proposed thermal insulation material. In these cases, the maximum allowable heat loss should be calculated in units of Btu / hr-ft (W/m) using C680, or similar program, where the units "feet" ("meter") refer to unit pipe length, and heat loss should then be multiplied by the pipe length to determine the maximum allowable heat loss in Btu / hr (W). This heat loss can then be divided by the product of the fluid's volumetric flow rate, density, and specific heat to determine the expected temperature drop over that pipe length. If the calculated temperature drop is unacceptably large, then the insulation thickness should be increased, usually by a 1/2 inch (13 mm) increment, and the calculations run again till the expected temperature drop is within an acceptable value.

(2) Calculations for Economic Thickness—These results of these calculations depend on a large number of design and financial variables.

The typical financial variables include:

(a) unit cost of energy,

(b) inflation rate for that type of energy,

(c) discount rate, effective income tax rate,

(d) physical plant depreciation period,

(e) new insulation depreciation period,

(f) incremental cost of plant capacity,

(g) percent of new insulation cost for maintenance,

(h) percent of annual fuel bill for physical plant maintenance,

(i) cost of either pipe insulation or board insulation,

(j) local labor rate, and

(k) complexity factor for the insulation system (that is,, lots of fittings and supports versus few fittings and supports).

The engineering variables are:

(a) fuel heating value,

(b) heating / cooling equipment efficiency,

(c) annual hours of operation,

(d) average annual ambient temperature,

(e) average annual wind speed, reference insulation thickness for payback calculations (usually zero),

(f) system operating temperature,

(g) at least three mean temperature – thermal conductivity values for the proposed thermal insulation material,

(h) proposed insulation jacketing type with a value for surface emittance, and

(i) proposed insulation thickness.

Some computer programs have the capability to accept each of these input variables and to perform these calculations for economic thickness. While default values are already included in the program for all the variables and at many times it is impossible for the design engineer to obtain some of these financial variables, it is recommended that the designer make a concerted effort to get an approximate value for these three: unit energy cost, unit material cost, and unit labor cost. While it is impossible to predict the fuel inflation rate, it is recommended that the designer use a value that is acceptable to the client. It is also recommended that the designer make a concerted effort to get accurate values for all the above engineering variables.

(3) Personnel Protection from Hot Surfaces—On high temperature systems, thermal insulation is frequently specified for the purpose of protecting workers from getting burned by the hot surfaces. To design such an insulation system, the designer can select the type of insulation with at least three mean temperatures—thermal conductivity values for this material, its thickness, and the type and thickness of the

insulation jacketing with a known emittance. He must know the process temperature, pipe size and orientation (or, if equipment, its orientation), and worst case ambient conditions (for outdoor applications, this is generally considered a very hot summer day with little or no wind but without the effects of solar radiation). Metal jacketing may be bare and shiny (as with aluminum or stainless steel) and therefore have a very low surface emittance. Or, it may be painted generally which usually gives it a higher surface emittance value. Everything else being equal, a low emittance (that is, < 0.2) will give a significantly higher surface temperature than a high emittance (that is, > 0.8) surface. Consequently, the insulation with the low emittance jacketing will need to be thicker than the same insulation material, on the same system, with a high emittance jacketing. While there is no universally agreed upon maximum allowable insulation surface temperature for personnel protection, 140°F (60°C) is frequently specified for metal jacketed systems. Most metals, such as aluminum, stainless steel, and carbon steel, have very high values of thermal diffusivity and therefore transfer heat quickly to other solids which come in contact with it, such as to human skin. Further, thickness metal will have a higher burn potential than a thinner metal, everything else being equal. For insulation systems with low diffusivity jacketing materials, such as conventional insulation covered with fabric and mastics or such as removable insulation blankets with fabric jacketing, the maximum safe surface temperature may be much higher than 140°F (60°C), perhaps as high 180° F (82°C). Hence, for these systems with a fabric jacket, less insulation thickness would be required for personnel protection than if they had a metal jacket. The multi-laminate jacketing materials fall somewhere in between conventional metal and fabric in terms of personnel protection, burn potential, and minimum required insulation thickness to provide personnel protection.

6.5.1.2 Insulation thickness required for a long run of pipe may be different than those required for economic thickness and may require special calculation of allowable temperature drop in a worst-case situation. Also, thicknesses required to maintain critical temperatures, noise control, and fire protection may be different than those calculated for economic thickness.

6.5.1.3 There are several computer software programs that can be used to calculate heat loss, economic thickness, and/or personnel protection such as ASTM Practice C680 or the NAIMA 3E Plus[8] program available from the U.S. Department of Energy (DOE) or the North American Insulation Manufacturers Association (NAIMA), free of charge, at www.pipeinsulation.org. This computer program has default values to represent typically used values. These defaults may need to be modified for specific use based on the plant's local economics and location. When using the 3E Plus[8] program the user should contact the insulation manufacturer to verify the appropriate thermal conductivity values to be used.

6.5.2 *Cold Surfaces*—Usually the cost of removing Btus (heat gain) by refrigeration is greater than the cost of producing process Btus (heat loss) by heat-generating equipment; therefore, the heat gain in cold processes should be minimized. The typical rule of thumb is to provide sufficient insulation to maintain an 8 to 10 Btu /h-ft^2 (27 to 34 W/m^{2}K) (where the ft^2 (m^2) units refer to outside insulation surface area) heat gain to the cold process. The design ambient temperature and wind conditions as mentioned in 6.2.3 and 6.2.4 should be used when calculating the insulation thickness.

6.5.3 *Condensation Prevention:*

6.5.3.1 For most indoor and a few outdoor applications, condensation control is necessary to avoid water damage to equipment, prevention of corrosion, and mold growth. Therefore, when determining the insulation thickness, the ambient conditions (that is, average dry bulb temperature during cooling conditions, relative humidity at that dry bulb temperature, and lowest expected wind speed) along with the process temperature, surface emittance, and area ventilation determine the required thickness of insulation. The insulation system should be designed so that the surface temperature of the insulation system is kept above the dew point of the ambient air. This will keep condensation from forming on the outer surface of the insulation and, hence, avoid safety hazards and dripping condensate on buildings or electrical equipment. It is essential to agree on what percentage (%) of time condensation is acceptable. It should be noted that as with calculations for minimum insulation thickness on hot surfaces where personnel protection is the design goal, in designing the minimum insulation thickness to prevent surface condensation on a cold service line, the jacketing surface emittance is a very important variable. For a given set of design conditions, a jacketing with a low surface emittance will be more likely to result in surface condensation that the same with a high surface emittance. Hence, the use painted jacketing or fabric with mastics, both of which typically have high surface emittance values, will not require as great insulation thickness as the use of shiny metal jacketing (that is, which usually has a very low value of surface emittance).

6.5.3.2 In hot, outdoor, (that is, unconditioned) humid environments and during rain, it is virtually impossible to prevent condensation 100 % of the time. Uneconomical insulation thickness would be required to achieve this. If the insulation thickness is designed to allow for an 8 to 10 Btu/hr-ft^2 (25.2 to 31.5 W/m^2) heat gain, this will be sufficient to prevent condensation the majority of the time.

6.5.4 *Freeze Protection/Winterization*—Most applications needing freeze protection are heat traced and insulated or just insulated. Heat-tracing manufacturers have guidelines for the amount and type of insulation required versus how much heat tracing is required. Rigid insulation needs to be increased one size to allow for the heat tracer, whereas compressible materials may not require over sizing to allow for the heat tracing. Compressible insulation fits snugly around the pipe without an annular space, and therefore, these systems may require an aluminum tape or heat transfer cement to transfer heat by conduction from tracer to pipe or equipment. Rigid type of insulation on the other hand forms annular space, which is heated by the tracer and so the heat is transferred from tracer to pipe or equipment by a combination of convection,

[8] A registered trademark of NAIMA (North American Insulation Manufacturers Association) 11 Canal Center Plaza, Suite 103 Alexandria, VA 22314.

radiation, and conduction. Worst-case ambient conditions should be used for determining the sizing of the tracer and calculating the insulation thickness for winterization or freeze protection.

7. Insulation System Application Methods

7.1 *General:*

7.1.1 *On-Site Material Storage:*

7.1.1.1 On-site storage of insulation and accessory materials should provide adequate protection from damage caused by water, moisture, and temperature. It is generally the insulation contractor's responsibility to furnish these storage facilities, although they may also be provided by the general contractor or plant owner. Storage facilities should be located in areas that provide adequate drainage. All flammable materials should be stored away from ignition sources such as welding operations. On-site storage can be broken down into two broad categories: long term and short term.

(1) Long-term storage facilities are required for large quantities of material that are required for the overall project. These facilities can be provided by:

(a) Temporary warehouses,

(b) Permanent warehouses, or

(c) Shipping trailers.

(2) Short-term storage is required for materials located at or near the installation work areas. Short-term storage is generally limited to material that will be used during a single workday. Short-term storage should keep materials off the ground and provide adequate protection against moisture contamination.

7.1.1.2 Storage temperatures for mastics, adhesives, and sealers should be within the temperature ranges specified by the material manufacturer. All materials that are improperly stored or exposed to temperatures outside the recommended temperature range should be removed from the site and replaced with new material.

7.1.1.3 Insulation and accessory materials that are susceptible to water damage and may become wet during storage should be protected from ground and dripping water, otherwise they should replaced with dry material should they become wet. This practice applies to hygroscopic materials such as calcium silicate, dry mix materials such as insulating and finishing cements, and fibrous materials that are not treated for water repellency. Cellular glass and materials that are treated for water repellency, such as expanded perlite and some mineral wool, may not need to be replaced provided they are allowed to air dry before installation and there is no physical deterioration.

7.1.2 *Protection of Installed Materials:*

7.1.2.1 Installed insulation materials should have the required permanent weather protection applied before the conclusion of each day of work. If not possible, then temporary weather protection should be provided for any insulation left exposed at the end of the workday. Temporary protection should be provided during the workday when exposed insulation could be damaged as a result of rain or other forms of atmospheric moisture. Adequacy of temporary protection should be the responsibility of the insulation contractor.

7.1.2.2 Insulation materials that become wet because of missing or inadequate weather protection, either temporary or permanent, should be removed and replaced with dry insulation. Wet insulation should be discarded and not reused. This applies to hygroscopic insulation as well as fibrous materials that are not treated for water repellency. Cellular glass and materials that are treated for water repellency may not need to be replaced provided they are allowed to air dry before application of permanent weather protection, including vapor-retardant systems, and there is no physical degradation.

7.1.3 *Protection of Adjacent Surfaces and Components*—Care should be exercised in the handling and application of materials, particularly mastic coatings, so as not to splatter concrete foundations, paving, structural steel, equipment, piping, gage glasses, instruments, machined surfaces, valve stems, and packing.

7.1.4 *Release for Insulation System Application:*

7.1.4.1 The insulation application should not be allowed to proceed until after the following steps have been completed:

(1) All required hydrostatic and pneumatic pressure testing;

(2) Application of required substrate protective coating systems, including touch-up of previously applied coatings; and

(3) Installation and testing of tracing systems.

7.1.4.2 When required by the general contractor or plant owner, insulation work may proceed before completion of system pressure testing, provided that all welds, flanges, and threaded connections are left exposed until testing and inspection is complete. Adequate weather protection should be provided at all insulation terminations. However, this practice should be avoided if at all possible, since it adds considerable cost to the installation and increases the probability that insulation will be damaged.

7.1.4.3 Authorization to proceed with insulation work should be in writing from the responsible authority.

7.1.5 *Health, Safety, and Environmental:*

7.1.5.1 All work activities associated with insulation work, including new installations, repair, removal, and retrofit, should be performed in accordance with applicable federal, state, and local laws and regulations, in addition to safety regulations established by the plant owner and general contractor. Health and safety precautions and procedures established by the material manufacturers should be observed. This includes information contained in product data sheets, application procedures, and MSDS sheets.

7.1.5.2 It is recommended that insulation work activities be performed when piping and equipment systems are not in service. When work must be performed on systems that are in service, special precautions should take into consideration exposure temperatures, hazardous processes, high pressures, and other extraordinary conditions. It is beyond the scope of this guide to define the nature and extent of such special precautions.

7.1.5.3 It is also beyond the scope of this guide to define the special requirements associated with work involving asbestos-containing materials or materials that have been contaminated with hazardous compounds. Such work is generally limited to existing facilities that are being upgraded in which tie-ins are being made or facilities that are being demolished. Consideration should be given to how the removal is done so that when new materials are joined with existing materials, the integrity of the insulation system is maintained.

7.1.6 *General Housekeeping and Disposal:*

7.1.6.1 Housekeeping and material disposal requirements will vary from facility to facility based on general contractor or plant-specific practices, as well as applicable federal, state, and local laws and regulations. The following are some common practices:

(1) All mastic overspray and splatter should be cleaned up as soon as it occurs;

(2) All flammable materials should be stored away from ignition sources, such as welding operations;

(3) Construction debris resulting from the insulation work should be container stored at the end of the workday and removed from the work area on a regular basis; and

(4) All material, scraps, boxes, scaffolding, and so forth should be removed from the site when work has been completed.

7.1.6.2 Used or spent containers and waste from solvent-borne mastics, adhesives, and sealers may need to be handled as hazardous waste as required by applicable federal, state, and local laws and regulations. Individual facilities may also have specific requirements regarding the handling and disposal of these waste materials.

7.2 *Application of Insulation Materials:*

7.2.1 *General:*

7.2.1.1 Insulation materials should be applied as specified to achieve the desired system performance.

7.2.1.2 While hot insulation systems can be somewhat more forgiving of errors or shortcomings in installation methods and procedures, the same cannot be said for cold insulation systems, especially when operating at subfreezing temperatures. When thermal bridging occurs or vapor-retardant systems fail to perform, icing will occur, followed by additional insulation system degradation.

7.2.1.3 The life expectancy of the facility needs to be considered when specifying materials and installation methods. Requirements for temporary, demonstration, or pilot plant facilities will be generally less demanding than those for permanent facilities.

7.2.1.4 Insulation should not be applied to wet surfaces or surfaces in which there is visible evidence of oil or grease until those surfaces have been cleaned and dried.

7.2.1.5 The use of broken or damaged insulation should not be allowed. However, insulation with damaged ends may be used if the ends are cut square.

7.2.1.6 Care should be taken in applying materials so as not to damage protective coatings on the surfaces to be insulated.

7.2.2 *Layering Requirements:*

7.2.2.1 The number of insulation material layers required for a system is determined by one or more of several factors:

(1) Commercial availability of material in a single layer,

(2) Insulation system design involving two or more materials not furnished as a composite,

(3) Insulation system design to limit heat loss or heat gain through joints resulting from material or substrate shrinkage or expansion at operating temperature,

(4) Insulation system design to limit stresses in a material layer at operating temperature,

(5) Insulation system design for electric tracing to maintain interface temperature within limits of the tracer when operating temperatures would otherwise exceed tracer limits, and

(6) Size of the external stiffeners on the flue, duct, or equipment.

7.2.2.2 The requirements for multiple insulation layers should be defined by the specific insulation design. When such requirements are not defined, the following may be used as a guideline:

(1) Insulation for heat conservation is provided as multiple layers when operating temperatures exceed 600°F (315°C),

(2) Layering requirements for cold-service applications will vary with the material selection (based on the dimensional change of the material at maximum/minimum temperature), and

(3) Insulation for personnel protection or where insulation is provided to protect the process from upsets resulting from sudden swings in ambient temperature are generally applied as a single layer within the constraints of material availability.

7.2.3 *Insulation Supports:*

7.2.3.1 Insulation supports are required for vertical and horizontal equipment. Insulation supports are also required for vertical and diagonal piping located at an angle of 45° or greater from horizontal. Insulation supports for equipment are generally provided by the equipment fabricator. Insulation supports for piping may be provided either as rings or clips by the piping fabricator or as bolt-on rings field installed by the insulation contractor. In some instances, it may be necessary for the insulation contractor to provide additional bolt-on support rings in the field, even though the piping is furnished with shop-welded supports.

7.2.3.2 Bolt-on support rings, which are subject to the approval of the purchaser, should satisfy the following criteria:

(1) Material of construction should be compatible with the piping;

(2) Plate thickness should be 3⁄16 in. (5 mm) minimum; and

(3) Support ring width should not be greater than insulation thickness minus ½ in. (13 mm) for hot application and thickness minus 1 in. (25 mm) for cold application. However, when connections are large enough to support insulation, the plate width should not be less than ¾ in. (19 mm), regardless of insulation thickness.

7.2.3.3 Location of piping insulation support should consider the following:

(1) Insulation supports are required above all flanged connections, regardless of spacing. Supports should be located one stud bolt length plus 1 in. (25 mm) from the back of the flange.

(2) Insulation supports are required above all elbows and tees when the uninterrupted piping run length is equal to or greater than 15 ft (4.6 m). However, support spacing should never be greater than that required for insulation expansion and contraction joints.

(3) Piping branch connections, instrument connections, and piping supports, such as trunnions in vertical and diagonal piping, also function as insulation support points.

7.2.4 *Insulation Expansion/Contraction Joints:*

7.2.4.1 Consideration needs to be given to rates of expansion and contraction between insulation materials and the insulated substrates to avoid direct heat flow paths from occurring in the insulation system. Insulation expansion and contraction joints are provided to compensate for these different rates of movement.

7.2.4.2 Insulation expansion and contraction joints should be designed and spaced to allow ½ to ¾ in. (13 to 19 mm) movement in each joint.

7.2.4.3 Insulation expansion/contraction joints should be provided beneath all insulation support points except supports at the bottom of vertical equipment, supports at the bottom of vertical or diagonal piping runs, and supports directly above flanged components.

7.2.4.4 Insulation system expansion joints should be provided for horizontal equipment and piping in services operating above ambient when insulated using rigid materials, such as calcium silicate, cellular glass, and expanded perlite. Expansion joints typically consist of fibrous insulation, which is compressed during installation. Insulation may be glass fiber mat without binders, silica fiber mat, or ceramic fiber blanket folded in a U-shape and wired in place at the bottom of the fold. Insulation may also be loose mineral wool, packed tightly. However, resin bonded fiber glass and mineral wool should be used only as recommended by the manufacturer.

7.2.4.5 Insulation expansion joint spacing should be determined for the specific insulation design, including considerations of insulation material shrinkage at elevated temperatures. When such spacing is not provided, the spacing in Table 4, based on ¾-in. (20-mm) expansion joint movement, may be used as a guideline for services operating above ambient.

7.2.4.6 Insulation system contraction joints should be provided for horizontal equipment and piping insulated with rigid materials in services operating below ambient. Contraction joints typically consist of low density < 2 pcf (32 kg/m^3) fibrous materials, such as glass fiber blanket or loose mineral fibers, either glass fibers or mineral wool. Whether contraction joint material is packed loose or in compression depends on the relative rates of contraction between the insulation materials and the insulated substrate. Insulation materials, such as polyisocyanurate insulation, that have higher coefficients of contraction than steel should have the contraction joint material installed in compression. Insulation materials, such as cellular glass, that have coefficients of contraction lower than steel should have the contraction joint material installed with minimum compression. Insulation contraction joint spacing should be specified for the specific insulation design, including considerations of differential rates of contraction between insulation material and the insulated substrate. When such spacing is not provided, the spacing in Table 5 may be used as a guideline for services operating below ambient. Spacing is based on allowing ½-in. (15-mm) movement in the contraction joint for both polyisocyanurate foam and cellular glass. Joint design should consider that polyisocyanurate will contract more than the insulated substrate, while cellular glass will contract less.

TABLE 4 Maximum Expansion Joint Spacing

Operating Temperature, °F (C)	Maximum Expansion Joint Spacing, Linear Feet (Meters)	
	Ferritic Steel	Austenitic Steel
200 (93.3)	75 (22.9)	51 (15.6)
300 (149)	41 (12.5)	28 (8.6)
400 (204.4)	27 (8.3)	19 (5.6)
500 (260)	20 (6.1)	15 (4.6)
600 (315)	16 (9.9)	12 (3.7)
700 (371)	12 (3.7)	10 (3.1)
800 (427)	12 (3.7)	8 (2.5)
900 (482.6)	10 (3.1)	7 (2.2)
1000 (538)	10 (3.1)	6 (1.8)

TABLE 5 Maximum Contraction Joint Spacing

Operating Temperature, °F (C)	Maximum Contraction Joint Spacing, Linear feet (Meters)			
	Ferritic Steel		Austenitic Steel	
	Cellular Glass	PIR Foam	Cellular Glass	PIR Foam
0 (-18)	200 (61)	37 (11.3)	113 (34.4)	43 (13.1)
-50 (-46)	118 (36)	22 (6.7)	66 (20.1)	25 (7.6)
-100 (-73.3)	N/A	N/A	47 (14.3)	18 (5.5)
-150 (-101)	N/A	N/A	36 (11)	14 (4.3)
-200 (-129)	N/A	N/A	30 (9.1)	11 (3.3)
-250 (-156.7)	N/A	N/A	26 (7.9)	8 (2.5)
-300 (-184.5)	N/A	N/A	23 (7)	8 (2.5)

7.2.4.7 The following coefficients of expansion may be used to calculate expansion and contraction joint spacing:

Coefficients of Expansion

	10^{-6} in/in°F		10^{-6} in/in°F
Carbon Steel	8.3	Cellular Glass Insulation	5
Stainless Steel	10	Polyisocyanurate Insulation	32
Aluminum	13	Polystyrene foam	35
Copper	8.4	Polyurethane (PUR)	32

7.2.4.8 An additional concern regarding insulation contraction joints in services operating below ambient is maintaining continuity of the vapor-retardant system over the joint during both contraction and expansion. This should be defined by the selection of both insulation and vapor-retardant materials over the joints.

7.2.5 *Insulation Terminations at Flanged Components:*

7.2.5.1 Insulation at flanged components should be terminated a sufficient distance back from the flanges to allow removal of bolting without disturbing the adjacent insulation. The minimum distance should be equal to the bolt length plus 1 in. (25 mm).

7.2.5.2 Insulation terminations at flanged components should be finished to maintain system integrity even when the flanged components are scheduled to be insulated.

7.2.6 *Pipe Insulation Systems—Services Above Ambient:*

7.2.6.1 Sectional insulation should be installed using staggered joint construction in which the end joint of one half section is at the midpoint of the opposite half section. This application technique allows the insulation system, when secured in place, to function as a single section of insulation, which allows expansion joints to function as intended.

Similarly, segmental insulation should also be installed using staggered joint construction.

7.2.6.2 Unlike 7.2.6.1, one piece or hinged joint pipe insulation, typically molded fibrous materials or those hinged by a factory applied vapor retarder, should be are not installed with staggered joints but with end joints in compression.

7.2.6.3 When multiple layers of insulation are required, each layer needs to be installed such that joints longitudinal and circumferential in successive layers do not coincide with those in the preceding layers, except where they intersect at right angles. It is also recommended that expansion joints in one layer be offset from those in the adjacent layer to eliminate direct heat paths from the insulated surface to the outside of the insulation system.

7.2.6.4 Pipe insulation should be secured in place with a minimum of two securement devices per section of insulation. Securement may be by means of tape, wire, or bands, or some combination thereof. Securement selection is based on the type of insulation material involved, as well as size and location within the system. The following are some guidelines for selecting securement devices:

(1) Tape—Generally used on insulation that could be cut by wire, such as cellular glass and foam plastic. It may also be used to secure glass fiber and mineral wool insulation. Its use is also normally limited to pipe sizes NPS 6 and smaller. Tape is usually furnished ½-in (13-mm) inch wide and reinforced with glass or polyester fibers.

(2) Stainless Steel Wire—Generally used on insulation that is less susceptible to being cut by wire, such as calcium silicate, expanded perlite, and mineral wool. However, when wire is used to secure expanded perlite, the wire diameter should be greater than 0.052 in. (1.32 mm) to avoid cutting into the insulation. While the use of wire is normally limited to pipe sizes NPS 12 and smaller, wire is commonly used to secure inner layers of this insulation within reasonable limits. Stainless steel is the recommended wire material.

(3) Stainless Steel Bands—Used to secure insulation not secured by either tape or wire. Normal band size is ½ in. (13 mm) wide by 0.020-in. (0.5-mm) thickness, although ¾-in. (19-mm) wide bands should be used for large-diameter insulation over NPS 30. Stainless steel is the recommended banding material.

7.2.6.5 Insulation should be applied so that joints tightly fit together and are secured in place using the specified securement material. Tape should be applied long enough to overlap itself 6 in. (150 mm) or 25 %, whichever is less. Ends of wire loops should be tightly twisted together and embedded flush with the insulation surface. Bands should be machine tightened and sealed in place while in tension.

7.2.6.6 Fittings, such as elbows, tees, caps, and reducers, should be insulated with the same material and thickness as used on adjoining pipe. Molded expanded perlite, glass fiber, or mineral wool insulation for fittings may also be used within the temperature limitations of the particular material. From a performance standpoint, molded fitting covers are the preferred method and should be used wherever practical. When fitting insulation is fabricated, it should be in accordance with the general guidelines of Practice C450, including the fabrication adjunct. Particular attention should be paid to the number of segments used to fabricate elbow covers. Additionally, the high points along the outside radius should be rasped down. These factors can adversely affect the fit of shop-fabricated metal gore covers as well as die-formed and molded covers.

7.2.7 *Pipe Insulation Systems—Services Below Ambient:*

7.2.7.1 All abutting surfaces of each segment in single-layer insulation and at a minimum the outer layer in multiple-layer insulation should be fully coated with butyl rubber joint sealant. It is recommended that the insulation material supplier be contacted to obtain recommendations as to if the joints of all inner layer(s) insulation may require joints to be sealed. Thickness of joint sealant after installation should as thin and even as possible while maintaining good adhesion and the thickness should not exceed 1/8 in. (0.3 mm). Abutting surfaces of inner layers do not need to be sealed unless required by the insulation material manufacturer.

7.2.7.2 *Insulation Joints Sealants:*

(1) Sealants in insulation work function primarily as water and vapor seals. In many applications, however, they may also function as adhesives and expansion joints with metal, masonry, cellular glass, and so forth. The requirements for this type of product include low shrinkage, excellent adhesion, and permanent flexibility. Some sealants are virtually 100 % nonvolatile and skin over by oxidation, remaining soft and flexible under the skin. Others contain polymers dissolved or dispersed in varying amounts of volatile solvents. These exhibit somewhat greater shrinkage and dry by evaporation of the solvent.

(2) Sealants used in the joints of cold insulation should be limited to only enough sealant to seal the joint, avoiding excess thickness that could create a thermal-short causing unnecessary condensation to the outer surfaces of the insulation jacketing system. Sealants should not be used to fill voids caused by damage or improperly fitting insulation. Sealants can also be used as bedding compounds under the insulation to prevent abrasion, corrosion, and/or stop moisture movement.

7.2.7.3 When multiple-layer insulation is required, fitting insulation for elbows and tees should be provided with ship lap ends that will allow the insulation to stagger 1.0 in. (25 mm) minimum at the cover.

7.2.7.4 All pipe fittings, flanges, valves, and other system components should be fully insulated. Insulated valves should have insulation terminated a sufficient distance below the packing gland to allow packing adjustment. Extended bonnet valves allow insulation to be terminated at a location where the occurrence of condensation is minimized. For services below -100°F (-73.7°C), the use of extended bonnet valves are recommended.

7.2.7.5 Vapor stops, which seal the insulation to the pipe or equipment, should be installed at all insulation terminations. These include, but are not limited to, flanges, pipe supports, instrument connections, uninsulated vents, and relief valves. Extended bonnet valves allow insulation to be terminated at a location in which the occurrence of condensation is minimized.

7.2.7.6 Metal parts (except valve stems) that protrude through the insulation, such as uninsulated branch connections and support hangers, should be insulated from the outer surface of the piping insulation for a distance of approximately three times the thickness required for the protruding part. The insulation thickness for protruding parts should be based on the fluid temperature of the component to which the part is attached and the equivalent pipe size determined as follows:

(1) For cylindrical attachments, the nearest given pipe size corresponding to the diameter of the attachment should be used and

(2) For structural shapes, the longest dimension of the nominal section size corresponding to a given pipe size should be used (that is, a 6 by 4 angle is equivalent to NPS 6 pipe).

7.2.7.7 Voids in insulation covers for flanges and valves should be filled with loose mineral fiber insulation (that is, either mineral wool or fibrous glass, selected based on its Maximum Use Temperature). Alternately, voids may be filled with field-frothed polyurethane foam. However, care should be exercised in providing adequate venting to avoid damaging the insulation cover.

7.2.8 *Pipe Insulation Systems—Considerations for Acoustical Service:*

7.2.8.1 Mineral wool, glass fiber or elastomeric foam should be installed the same as required for applications in other services operating above ambient, with the exceptions and clarifications described in the following.

7.2.8.2 All pipe, fittings, flanges, valves, and support trunnions need to be fully insulated. Pipe support clamps that extend outside the pipe insulation should also be insulated fully, including insulation terminated on the hanger rod.

7.2.8.3 All insulation should be installed with tightly butted joints using contact adhesive on all butt joint surfaces. Visible gaps are not acceptable. Insulation should be refitted, trimmed to fit, or replaced. Insulating cement or hydraulic setting cement should never be used to fill voids or point up insulation in acoustical service.

7.2.8.4 All acoustical insulation should be secured with bands. Tape and wire should not be used for insulation securement.

7.2.8.5 All acoustical insulation should be finished with either acoustical jacketing or acoustical mastic.

7.2.8.6 Acoustical jacketing should be installed in accordance with the relevant portions of Section 8 and the following:

(1) All projections through the jacketing should be caulked with a heavy bead of suitable sealer.

(2) All jacketing should be secured with stainless steel bands. Screws should not be used for any jacket securement.

(3) A heavy bead of suitable sealer should be applied between all overlapping jacket surfaces to provide a continuous seal between all laps.

(4) All jacketing should be installed without evidence of wrinkling in the overlaps.

7.2.8.7 Membrane-reinforced acoustical mastic may be used on compound surfaces or complex shapes where the use of metal jacketing is not practical. Application should be in accordance with the mastic manufacturer's instructions and the following:

(1) Substrate temperatures should be within the application temperature range established by the material manufacturer.

(2) Acoustical mastic should be applied in two layers, with a reinforcing membrane applied in between. While the first mastic coat is still tacky, the reinforcing membrane should be stretched taut and thoroughly embedded without warping or rupturing the weave. All membrane seams should be overlapped 3 in. (75 mm) minimum. The second coat of mastic should be applied before the first coat dries and should completely cover the membrane.

(3) All outside corners of insulation should be rounded and the acoustical mastic provided with a double layer of reinforcing membrane.

(4) Acoustical mastic should be terminated approximately 1/4 in. (6 mm) short of all metallic protrusions through the insulation system. A sufficient application of sealant should be used to seal the system between acoustical mastic and the protrusion.

7.2.9 *Pipe Insulation Systems—Considerations for Traced Services:*

7.2.9.1 When insulating traced pipe, consideration should be given to the distribution (transfer) of heat from the tracer to the entire pipe surface.

7.2.9.2 Insulation should be oversized for most traced applications. The exception is flat electric tracing tapes. It is recommended that the insulation be one size larger than the pipe size. Actual over sizing requirements will depend on the number of tracers and the use of tracer channels. Oversized insulation may be stabilized on the pipe using block insulation spacers. Spacers should be approximately 9 in. (230 mm) long by 1 in, (25 mm) wide with the depth as required. Spacers should be centered at the circumferential joints, with a 9 in. (230 mm) space between spacer blocks along the pipe.

7.2.9.3 When soft, blanket-type insulation is used, over sizing the insulation is not practical. The tracer should be covered with foil tape or equivalent before installing the insulation. Secure the foil in place using adhesive-backed foil tape, temperature permitting. This foil will help direct the heat from the tracer into the pipe rather then the air space.

7.2.9.4 Oversized insulation on vertical insulation requires the use of flue stops to prevent a chimney effect. Flue stops need to be provided on approximate four foot centers. Flue stops should consist of heat transfer cement, applied a minimum 1 in. (25 mm) wide, completely filling the void between the pipe and insulation. The heat transfer cement should be suitable for the operating temperatures of the pipe and tracer.

7.2.9.5 All tracing connections should be located outside the insulation system.

7.2.9.6 Steam tracer loops and tubing located outside the insulation system should be insulated when required for personnel protection or when heat losses from uninsulated surfaces are not allowed. Tubing should be insulated with fiberglass tape spiral wound onto the tubing. Fiberglass tape should be applied to a thickness of approximately 1/2 in. (13 mm) by applying either with a 50 % overlap or in multiple layers or a combination of both. Fiberglass tape should be finished with a coat of weather barrier mastic.

7.2.9.7 The use of screws for jacket securement should not be allowed on any electric-traced systems.

7.2.9.8 Where potential process hot spots cannot be tolerated, the steam tracers should be insulated with fiberglass tape 1/4 in. (6 mm) by applying 1/8 in. (3.175 mm) thick tape with a 50 % overlap. The insulated tubing can then be secured to the pipe with wire or bands. The traced piping system can then be insulated with oversized insulation and stabilized using block insulation spacers.

7.2.10 *Equipment Insulation Systems—Services Above Ambient:*

7.2.10.1 Horizontal equipment with shell diameters of 30 in. (760 mm) and less may have shell insulation extended to cover the heads and blocked in with an insulation disk. Horizontal equipment with shell diameters greater than 30 in. (760 mm) and all exposed heads on vertical equipment should be covered with block insulation cut to fit the head curvature. Heads inside vessel skirts may be insulated with metal-mesh mineral wool blanket.

7.2.10.2 All equipment insulation should be secured in place with a minimum of two stainless steel bands per section of insulation. Stainless steel band sizes should be 1/2 in. (13 mm) or larger diameters. Band spacing should be a minimum of 12-in. (300-mm) centers.

7.2.10.3 Other requirements defined for piping insulation systems are also applicable to equipment insulation systems.

7.2.11 *Equipment Insulation Systems—Services Below Ambient:*

7.2.11.1 All abutting surfaces of each segment in single-layer insulation and the outer layer in multiple-layer insulation should be fully coated with butyl rubber an approved joint sealant. Thickness of joint sealant after installation should be as thin and even as possible while maintaining good adhesion. Thickness should not exceed 1/8 in. (0.3 mm). Abutting surfaces of inner layers do not need to be sealed unless required by the insulation material manufacturer.

7.2.11.2 All equipment nozzles, manways, and handholes, including covers, should be fully insulated.

7.2.11.3 Vapor stops sealing the insulation to the substrate should be installed at all insulation terminations. These include, but are not limited to, clips, brackets, lugs, saddles, skirts, support trunnions, and instrument connections.

7.2.11.4 Horizontal equipment with shell diameters of 30 in. (760 mm) and less may have shell insulation extended to cover the heads and blocked in with an insulation disk. Horizontal equipment with shell diameters greater than 30 in. (760 mm) and all heads on vertical equipment should be covered with block insulation cut to fit the head curvature. To ensure a tight fit between head insulation segments, it is recommended that the segments be shop fabricated.

7.2.11.5 Metal parts that protrude through the insulation should be insulated the same as required for piping. For equipment supported by short lugs from structural steel framework, it may be necessary to extend the insulation onto the structural steel.

7.2.11.6 Other requirements defined for piping insulation systems are also applicable to equipment insulation systems.

7.2.12 *Machinery Insulation Systems:*

7.2.12.1 Machinery, which includes pumps, compressors and turbines, operating in services above ambient, may be insulated, when required, using one or a combination of the following methods:

(1) Flexible, removable blanket insulation covers;

(2) Rigid insulation blocks, such as calcium silicate, finished with hydraulic setting cement and weatherproofed with either reinforced mastic or a lagging cloth;

(3) Insulating cement, reinforced with wire mesh, finished with hydraulic setting cement and weatherproofed with either reinforced mastic or lagging cloth; and

(4) Sheet metal enclosures lined with fibrous insulation.

7.2.12.2 *Removable/Reusable Insulation Covers:*

(1) The covers used to insulate and protect valves, equipment, and piping are fabricated from silicone rubber-impregnated glass fabric over an insulation material and held in place with either stainless hog ring staples or sewing thread. For high-caustic areas, coated glass fabric is used. On most designs, stainless steel or monel knit mesh wire is placed over the cover for extra protection.

(2) Advantages—Flexible pads are easy to install on irregular surfaces, require less labor than standard rigid insulation, give both thermal and acoustical protection, offer fire protection, and allow easy access for inspection and reinsulation (Such as Tedlar[9], Hypalon[10] and TFE-fluorocarbon.)

(3) Application—Removable/reusable covers can be fabricated off-site to reduce the labor cost or fabricated on-site. They are usually attached with tie wire through lacing hooks or with straps sewn to the cover itself.

(4) Laminates of aluminum or stainless foil or both to fabrics are used in the design of removable covers for special situations.

7.2.12.3 Large steam and gas turbines are generally insulated in accordance with the specifications and drawings of the equipment manufacturer. Deviations from these requirements should be avoided, since the manufacturer may consider the equipment performance warranty voided.

7.2.12.4 Small steam turbines are generally purchased with insulation covers furnished by the equipment manufacturer. When field installation is required, instructions by the manufacturer should be followed.

7.2.12.5 Pumps that require insulation for heat conservation, including heat-traced services, are usually insulated with flexible, removable covers, sheet metal enclosures, or reinforced insulating cement; finished with hydraulic setting cement; and weatherproofed. When cement is used on traced pumps, the tracing should be protected, such as by covering with foil tape, to prevent the cement from coming between the tracer and pump casing. When pumps require personnel protection, it may also be provided by one of these methods, or by other means, such as restricting access or providing expanded metal guards.

7.2.12.6 When pumps or other rotating equipment are insulated with cement, the following guidelines should be followed:

(1) Insulating cement should be applied by trowel filling all depressions for the entire depth to eliminate voids. The thickness of each application should not be any greater than that which will set on vertical surfaces without excessive cracking when dry.

[9] Tedlar is a registered trademark of DuPont.

[10] Hypalon is a registered trademark of DuPont.

(2) When the preceding layer is dry, additional applications can be made as required to achieve the specified thickness.

(3) Final application of insulating cement should have wire mesh embedded in the surface. When specified thickness exceeds 1 ½ in. (38 mm), cement should also be reinforced with one layer of wire mesh for each additional 1 ½ in. (38 mm), or part thereof, uniformly embedded midway through the thickness of the cement.

(4) When the insulating cement has thoroughly dried, a finish coat of hydraulic setting finishing cement should be applied to a thickness between ¼ and ½ in. (6 and 13 mm).

(5) The hydraulic setting cement should be finished with a membrane-reinforced, weather barrier mastic coating. When recommended by the coating manufacturer, the hydraulic cement should be coated with a suitable primer before application of the mastic.

7.2.12.7 Pumps or other rotating equipment operating below ambient that are insulated require additional considerations.

7.2.13 *Equipment Insulation Systems—Considerations for Acoustical Service*—Requirements defined for piping insulation systems are also applicable for equipment insulation systems.

7.2.14 *Equipment Insulation Systems—Considerations for Traced Services:*

7.2.14.1 The physical location of tracers and type of tracing provided will determine the type of insulation, rigid or flexible, and applications requirements for insulating traced equipment.

7.2.14.2 When equipment is traced with spirally wrapped tracers, the spacing (pitch) of the tracers will determine the need for spacer blocks between the tracing to provide adequate support for the insulation. Spacers should be fabricated from rigid block, 1 in. (25 mm) minimum width and thickness equal to the tracer height from the equipment surface. Length of spacer blocks will be determined by the curvature of the equipment surface.

7.2.14.3 When only the lower portion of the equipment is insulated, it may be practical to install an inner layer of insulation on the untraced area to provide a uniform diameter. This will allow for continuity of the insulation outer surface and weather barrier finish.

7.2.14.4 When equipment heads are traced, spacer blocks should be provided between the tracers, the same as required for equipment shells. Spacer blocks should always be provided on horizontal heads located near grade or working elevations and on all top heads. The blocks can be secured with a suitable adhesive or wire.

7.2.14.5 All tracing connections should be located outside the insulation system.

7.2.14.6 Steam tracer loops and tubing located outside the insulation system should be insulated when required for personnel protection because heat losses from uninsulated surfaces are not allowed. Tubing should be insulated with fiberglass tape spiral wound onto the tubing. Fiberglass tape should be applied to a thickness of approximately ½ in. (13 mm) by applying either with a 50 % overlap or in multiple layers or a combination of both. Fiberglass tape should be finished with a coat of weather barrier mastic.

7.2.14.7 Where potential hot spots cannot be tolerated, the steam tracers should be insulated with fiberglass tape spiral wound onto the tubing. Fiberglass tape should be applied to a thickness of approximately ¼ in. (6 mm) by applying ⅜ in. (3.175 mm) thick tape with a 50 % overlap. The traced equipment can then be insulated using insulation spacers as required.

7.2.15 *Storage Tank Insulation Systems—Services Above Ambient:*

7.2.15.1 Storage tanks operating above ambient are generally insulated using one or a combination of the following methods:

(1) Insulation boards are secured by pins, studs, or banding. Insulation is finished with a separate application of metallic jacketing, which may be secured by using the same studs, by banding, or by fastening to a subgirt system attached to the tank.

(2) Insulation and jacketing preassembled as a unit and secured to the tank sidewall by studs.

(3) Insulation boards adhered to metallic jacketing, furnished in unit lengths to match the sidewall heights, and secured in place with standing seams field formed around clips anchored to an independent cable system around the tank.

(4) Insulation boards adhered to metallic jacketing, curved to match the tank radius, and secured in place using wide banding, incorporating compression tensioning devices.

(5) Insulation boards or blocks secured to the tank roof by pins, studs, or elastomeric adhesives and finished with built-up roofing, membrane-reinforced mastics, elastomeric compounds, or other flexible coating compounds.

7.2.15.2 When engineered and prefabricated insulation systems are used, the installation should be in accordance with the system manufacturer's design and erection drawings. It may also be necessary to use an installation contractor approved by the system manufacturer.

7.2.16 *Storage Tank and Sphere Insulation Systems—Services Below Ambient:*

7.2.16.1 Storage tanks and spheres operating below ambient are generally insulated using one of the following methods:

(1) Cellular glass insulation bonded directly to surface using low-temperature elastomeric adhesive. This system is limited to services above -50°F (-45.5°C) -70°F (-57°C) and is generally preferred for spheres.

(2) Spray-applied polyisocyanurate foam insulation finished with vapor retardant mastic and separate weather resistant finish.

(3) Polyisocyanurate foam insulation field applied directly behind continuous, horizontal aluminum sheeting.

NOTE 3—This method is proprietary to certain tank fabricators.

(4) Cellular glass insulation or polyisocyanurate foam insulation boards banded in place and covered with vapor-retardant system and separate weather-resistant finish.

7.2.16.2 Metal parts that protrude through the insulation should be insulated the same as required for piping.

7.2.16.3 Other requirements defined for piping insulation systems are also applicable to equipment insulation systems.

7.2.17 *Precipitators, Ductwork, and Related Equipment:*

7.2.17.1 There are several different methods of insulating large flat surfaces such as precipitators and ductwork:

(1) Insulation applied directly against the surface to be insulated, with additional insulation added, as required to insulate over stiffeners. Metal jacketing (sometimes referred to as lagging) jacketing (often referred to as lagging for this application) is generally secured to a separate subgirt system. This allows the jacketing jacketing / lagging to be applied in a flat plane rather than follow the contours created by stiffeners.

(2) Insulation panel systems that are applied to a separate subgirt system so as to form a flat plane outside the stiffeners. Insulation panels consist of insulation material mechanically fastened to the metal jacketing / jacketing lagging. Insulation panel systems are generally engineered and prefabricated to fit a specific application.

(3) H-bar systems consist of a separate subgirt system comprised of H-sections attached to existing stiffeners or separate standoffs when required to form a flat plane. The insulation material is fitted in the H sections with the metal jacketing / jacketing lagging applied separately. The insulation material should be self supporting between the H-Bars when exposed to elevated process temperature and/or vibration of duct work. In some instances for example, horizontal applications may require supporting type stiff welded mesh between H-Bars to minimize insulation sag at elevated temperature and /or with vibration.

7.2.17.2 All topjacketing / jacketing lagging surfaces should be sloped to allow for water drainage. Insulation systems on top surfaces should also be designed to withstand walking loads without permanent deformation of the jacketing / jacketing lagging system.

7.2.17.3 All penetrations should be flashed. Flashing should allow for differential movements between the penetration and the jacketing / lagging jacketing. Flashing on top surfaces should extend to the high point of the surface to avoid water ponding on the uphill side of the penetration.

7.2.17.4 When insulation is not applied directly to the surface, thermal barriers (flue stops) should be provided between the surface being insulated and the hot face of the insulation. Thermal barriers should be installed at the top and bottom of all vertical surfaces. Intermediate thermal barriers are on 10-ft (3-m) maximum centers.

7.2.17.5 Galvanized facings on the hot sides of insulation systems should not be used for operating temperatures above 350°F (176.6°C). Carbon steel with a japanned finish or stainless steel should be used for these operating temperatures.

7.2.17.6 The use of 400 series stainless steel, self-drilling fasteners for attaching insulation panels directly to subgirts should be limited to operating temperatures less than 500°F (260°C). For temperatures above this, use 300 series stainless steel fasteners and separately drilled holes.

8. Protective Coverings and Methods of Application

8.1 *General:*

8.1.1 In any application of thermal insulation, insulation requires protection of some type from rain, snow, sleet, wind, ultraviolet solar radiation, mechanical damage, vapor passage, fire, chemical attack, or any combination of these. The protection can be metal, plastic, coated, and/or laminated composites, mastic coatings, or a combination of all of these depending upon the application, service, and economic requirements.

8.1.2 In the following sections are the components available.

8.2 *Metal Protective Jacketing or Lagging Systems:*

8.2.1 Metal jacketing materials are normally thin gauge with a factory applied moisture barrier and usually installed by the Asbestos Union (insulators). Metal lagging materials are normally heavier gauge materials that do not require a moisture barrier and is normally installed by Sheet Metal Union. those whose Primary material (usually the component of greatest thickness) is metal such as aluminum or stainless steel. The metal may be smooth, corrugated, embossed, painted, coated, or have a film laminate finish. Smooth aluminum and stainless steel through the reflection of light tend to emphasize areas of minor damage. It is advisable, particularly with large flat areas, to break up the reflecting surface by the use of corrugated sheet or material with a stucco embossed finish or both. Sheets with box or ribbed corrugations will have greater resistance to deformation than will flat sheet. The dimensions of the corrugation, pitch, and depth may be specified for interchangeably constant rigidity and control of sizes.

8.2.2 Aluminum was one of the first metals to be used as a jacketing material. In alloys 1100, 3003, 3004, 3105, 5005, and 5010 conforming to Specification B209 and tempers H14 (half hard) through H19 (full hard), it is still the single most widely used product for general purpose industrial installations. Thickness tolerances should conform to the standards adopted by the American Association of Aluminum Manufacturers.

8.2.3 The advantages of aluminum jacketing are low initial cost and easy workability. Its disadvantages are low chemical resistance in the alkaline, relatively low mechanical strength, low fire resistivity, a melt point of 1200°F (660°C), and low emittance values which may lead to higher surface temperatures that could cause a personnel hazard in high temperature systems or a lower surface temperature causing possible surface condensation on cold operating systems.

8.2.4 The advantages of painted aluminum are the coating can be selected to suit the environment offering improved corrosion resistance, substantially higher emittance values, and availability in a multitude of colors, moderate cost, and easy workability. Its disadvantage is that the thin paint film can be abraded relatively easily and degradation of the surface polymer may ultimately result in failure.

8.2.5 Clad aluminum (Alclad) is the result of a mechanical process wherein an aluminum alloy core is coated, before rolling, with aluminum anodic for its electrolytic protection against corrosion. The prime benefit of clad aluminum is its slightly better surface chemical resistance compared to unclad aluminum.

8.2.6 Aluminum that has been chemically cleaned, primed with a corrosion inhibitor, and then mill coated with a polyester or acrylic resin offers greater use flexibility and somewhat more protection at a higher cost.

8.2.7 Aluminum that has been chemically cleaned, primed with a corrosion inhibitor, and the surface laminated with a film of polyvinyl fluoride offers the additional advantage over painted aluminum of the film being twice the thickness of the paint coating, substantially higher emittance values, and imparting virtually a totally chemically resistant surface to the metal. The disadvantages of this type of system are that the film is still subjected to abrasion, it is more expensive, and to obtain the ultimate chemical resistance the film can offer, the metal edges must be treated or hemmed.

8.2.8 Stainless steel in types 304 and 316 has met with wide acceptance. These jacketing materials are prime grade stainless steels with a standard 2B mill finish for reduced glare. (Polished finishes can be obtained for special applications). These steels are of a special soft annealed temper for ease in field fabrication and conform to Specifications A167 and A240/A240M. Stainless offers high mechanical strength, excellent fire retardance (having a melt point of 2600°F (1427°C)), and excellent corrosion and weather resistance. Another advantage of stainless steel jacketing is its reusability for line inspection and relocation. Most products inadvertently spilled on the jacketing can be easily and effectively removed without adversely affecting the surface. Higher initial cost, more difficulty in handling and working with the material, and a relatively low emittance value are the disadvantages to be considered. Stainless flat sheets should have a ½ in. (13 mm) minimum hem formed at the laps to prevent injury to personnel.

8.2.9 Other steel jacketing materials that may be considered are a low-carbon cold-rolled steel that has a hot-dipped aluminum-zinc alloy coating applied to the outer surfaces for resistance to corrosion (the coating is composed of 55 % aluminum, 1.6 % silicon, and 43.4 % zinc) conforming to Specification A792/A792M or a steel with a G-90 hot-dipped galvanized coating conforming to Specification A653/A653M. The aluminum-zinc alloy-coated steel significantly outlasts regular galvanized steel in industrial atmospheres. Since it can be used at temperatures up to 600°F (315°C) without discoloration, and up to 1250°F (677°C) without heavy oxidation or scaling, it provides superior fire resistance and protection compared to aluminum. Aluminum-zinc alloy-coated steel is an alternative when the design considerations require greater mechanical strength and fire resistance than that offered by aluminum but at a cost that is less than stainless steel. This jacketing is not recommended for harsh acidic environments and should not be used if it comes in contact with lead, copper, or water runoff from a copper source. These products can also be painted for additional protection and enhanced appearance.

8.2.10 *Moisture Retarder*—Soluble salts present in some industrial insulations function as a weak electrolyte when the insulation becomes moist. With the metal pipe and the metal jacketing functioning as opposite poles, a low-voltage galvanic cell is formed that is detrimental to both poles. In addition, crevice or pitting type corrosion can arise from water trapped against the underside of the jacketing. This can occur even in the absence of any soluble salts or other chemicals originating from the insulation and even in the presence of a vapor retarder which isolates the metal jacketing from the insulation. To prevent these attacks on the inside surface of metal jacketing, the incorporation of a factory applied laminated moisture retarder is highly recommended. This may be accomplished by the use of either a 3 mil (0.008 mm) thick composite film of polyethylene and ethylene/methacrylic acid co-polymer. or one layer of 40-lb (65 g/m^2) virgin Kraft paper coated on one side with 1 or 3 mils (0.0025 or 0.008 mm) of polyethylene film that is heat laminated to 100 % of the metal surface. This moisture retarder is especially suited for service in which excessive amounts of moisture or chemicals contained in insulation may come in contact with the moisture retarder inside of the metal jacketing for extended periods of time.

8.2.11 *Application of Metal Jacketing:*

8.2.11.1 Lapped joints of metal jacketing should be arranged to shed water with the lap facing down at the 2 or 10 o'clock position on horizontal piping. It is recommended the metal be pre-rolled to fit the circumference snugly of the insulation to prevent fish-mouthing along the longitudinal lap. A ½ to 1 in. (12 to 25 mm) hem along the longitudinal lap may be added to the jacketing to prevent further fish-mouthing and give it a safety edge. All overlaps should be a minimum of 2 in. (50 mm), preferably 3 in. 75 mm) on larger diameters. Screws to secure the longitudinal lap on hot piping should be spaced on 4 in. (100 mm) centers. If additional securement is needed because of probable high winds or the jacketing is on cold piping or just preferred in lieu of screws, then banding should be applied on 9-in. (230-mm) centers and arranged so there is one band at each circumferential overlap. Where penetration of water may occur such as tees, pipe bends, and so forth, the joints should be weatherproofed with appropriate sealant.

8.2.11.2 Corrugated sheets should be considered as being particularly advantageous on tanks and vessels with diameters greater than 4 ft 6 in. (1.45 m) and on large flat surfaces. The side laps of most corrugated sheets should be overlapped at least one corrugation. The 1¼ in. (31.75 mm) corrugated sheets will require a minimum of two corrugations overlap. The ends of sheets should overlap a minimum of 3 in. (75 mm).

8.2.11.3 Depending on the design conditions (hot and cold, expansion, contraction, diameter, height, flat or curved surface, type of insulation, and so forth), the selection of fastening devices will vary. Some examples are: maximum usage of banding and minimal usage of screws on cold applications, the use of compression or expansion springs in conjunction with banding on hot application to maintain tension on banding at all times, and the use of studs or a subgirt system on large flat surfaces.

8.2.11.4 Because of lineal expansion, it may not be desirable for the circumferential laps of the sheets to be stitched together with screws. Where exposure to high winds is a possible factor, using a combination of screws on the side laps 6-in. (150-mm) centers commonly used), banding on 12- to 18-in. (300- to 460-mm) centers, and heavy-gage continuous stitching strip approximately 4 to 6 in. (100 to 150 mm) wide located circumferentially every 3 ft (0.9 m) behind the sheets is a possibility. Horizontal vessels with corrugated sheets need to be sealed at all circumferential laps. For no-weld situations, there can be cable systems that are applied circumferentially around a tank with the metal sheets attached to it by special fasteners.

8.2.11.5 As the metal jacketing may be exposed to wide variations of atmospheric temperature, adequate provisions should be made to accommodate thermal movement and restrict through-metal contact with the hot surface.

8.2.11.6 Two items that also need to be mentioned are S-clips and J-clips. Two S-clips per sheet between the lower and upper sheets on vertical tanks and vessels will help support and keep an even line on each course of sheets. If banding is used to help secure the metal sheets, J-clips are advantageous as they prevent the banding from slipping down during installation and while in and out of service. Clip length may be critical where excessive expansion on very hot and tall equipment is considered.

8.2.11.7 Smooth flat metal that is very thin should be avoided on large diameters not only because of reduced strength, but also because of the unsightly wavy appearance.

8.2.12 Preformed fitting covers of aluminum and stainless steel are available from manufacturers in the most common sizes. Shop fabricated Gored fittings are commonly used when preformed fitting covers are not available. When insulation fitting covers are fabricated, they should be in accordance with the general guidelines of Practice C450, including the fabrication adjunct. Particular attention should be paid to the number of segments used to fabricate elbow covers. Additionally, the high points along the outside radius should be rasped down. These factors can adversely affect the fit of shop-fabricated metal gore covers as well as die-formed metal covers. Best fits are obtained when molded insulation fitting covers are used. Application procedures for applying metal covers on fittings, flanges, valves, end caps, bevels, and gored heads can be obtained from metals supplier's individual data sheets.

8.2.13 Commonly used metal jacketing, thicknesses and fastening devices are shown in Tables 6-8.

TABLE 6 Commonly Used Metal Jacketing, Thicknesses and Fastening Devices

NOTE 1—Where abuse is a concern, consider insulation system compressive strength when determining jacketing thickness.

NOTE 2—In cold service application screws, staples or any other fastener capable of puncturing the under laying vapor retarder shall not be used. The preferred method of attachment is bands.

Minimum Thickness for Pipe Jacketing		
Minimum Allowable Aluminum Thickness (in.)		
Outer Insulation Diameter (in.)	Rigid Insulation	Non-Rigid Insulation
Up to 8	0.016	0.016
over 8 thru 11	0.016	0.020
over 11 thru 24	0.016	0.024
over 24 thru 36	0.020	0.032
over 36	0.024	0.040

Preformed fittings	0.024 in (0.60 mm)
Fastening Devices:	½ × 0.020-inch (13 × 0.50 mm) S.S. banding #8 × ½ inch (13 mm) S.S. pan or hex head, slotted screws (See Note 1)
Vessels, Tanks, Flat Surfaces	Thickness, inch (mm)
Deep corrugated or profiled sheets (1-¼-, 2-½-, 4 inch. box, etc.)	
Curved surfaces	0.020 (0.50), 0.024 (0.60)
Flat surfaces	0.032 (0.80), 0.040 (1.0)
Fastening Devices:	
Curved surfaces	¾ × 0.020-inch (19 × 0.50) S.S. banding Side laps #8 × ½-inch (13). S.S. pan or hex head slotted screws (See Note 2) Compression or expansion springs
Flat surfaces	Side laps ¾ inch (19) long, Type A Bortek point S.S. or zinc-plated self drilling or self-tapping stitching screws (See Note 2)
To subgirt	Minimum 1-inch (25). long #14 S.S. or zinc-plated self-drilling or self-tapping screws

8.3 *Nonmetallic Protective Jacketing Materials*—Nonmetallic protective jacketing materials are used when mechanical abuse resistance is not a prime requirement, chemical resistance is needed, or a jacket-type vapor retarder is desired. Laminated composite jacketing materials are manufactured from combinations of plastic films, bitumen, fabric scrims, and cloths selected to obtain the required performance characteristics. Plastic jacketing materials are manufactured in forms ranging from very soft and flexible to hard and rigid.

8.3.1 Nonmetallic protective jackets may contain a metallic foil, commonly aluminum, as a vapor-retarding component.

8.3.2 *Plastic Sheet:*

8.3.2.1 Extruded plastics of polyvinyl chloride (PVC) and chlorinated polyvinyl chloride (CPVC), as a sheet material used for a protective jacketing, give good resistance to water and caustics. The joints should be sealed with an adhesive as recommended by the jacketing manufacturer to make it more difficult for the entry of liquid water but consideration should also be given to the possible need for slip joints in the jacketing to account for expansion / contraction of the system. In most application for cold pipe or equipment, a vapor retarder separate from the jacketing in is needed.

8.3.2.2 *Advantages*—Plastic jacket is easy to form, cut, and fabricate. The jacket can be made in colors (for indoor use only) for color coding.

8.3.2.3 *Limitations*—Plastic jackets have low softening points +165°F (73.8°C) for PVC and +225°F (107.2°C) for CPVC.

8.3.2.4 Molded ell and tee covers can be formed from PVC and CPVC for quick application. These fitting covers are intended to compliment all jacketing systems, both metallic and nonmetallic.

8.3.2.5 *Application*—PVC and CPVC jackets should be cut and curled when applying to pipe diameters of 8 in. (200 mm) or smaller. Above 8 in. (200 mm), it can be cut on-site. The laps can be sealed with adhesive recommended by the manufacturer or PVC solvent welded cement to make it more difficult for the entry of liquid water but consideration must also be given to the possible need for slip joints in the jacketing to account for expansion / contraction of the system PVC solvent welded cement should be used only on thicknesses of 20 mils (0.05 mm) or heavier. For thinner plastic, use contact adhesive. In most applications for cold pipe or equipment, a vapor retarder separate from the jacketing is needed.

8.3.3 *Reinforced Plastics*—This group includes glass fiber-reinforced plastic (FRP).

TABLE 7 Commonly Used Metal Jacketing, Thicknesses (rigid insulation) and Fastening Devices

NOTE 1—In cold service application screws, staples or any other fastener capable of puncturing the under laying vapor retarder shall not be used. The preferred method of attachment is bands.

Stainless Steel Jacketing	
Piping	Thickness, in.
Up through 24-in. O.D. insulation	0.010 (0.25)
26 in. and larger	0.016 (0.40)
Preformed fittings	0.016 (0.40)
Fastening Devices:	½ × 0.020-inch (13 × 0.50) S.S. banding #8 × ½ inch (13) S.S. pan or hex head, slotted screws (See Note 1)
Vessels, Tanks, Flat Surfaces	Thickness, in.
Deep corrugated or profiled sheets (1-¼-, 2-½-, 4-in. box, etc.)	
Curved surfaces	0.010 (0.25), 0.016 (0.40)
Flat surfaces	0.016 (0.40), 0.020 (0.50)
Fastening Devices:	
Curved surfaces	¾ × 0.020-inch (19 × 0.50). S.S. banding Side laps #8- × ½ inch (19) S.S. hex head slotted screws Compression or expansion springs
Flat surfaces	Side laps ¾ inch long, Type A point S.S. drilling or self-tapping stitching screws
To subgirt	1 inch (25) long #14 S.S. or zinc-plated self-drilling or self-tapping screws

TABLE 8 Commonly Used Metal Jacketing, Thicknesses (rigid insulation) and Fastening Devices

NOTE 1—In cold service application screws, staples or any other fastener capable of puncturing the under laying vapor retarder shall not be used. The preferred method of attachment is bands.

Coated Steel Jacketing[A]	
Piping	Thickness, inch (mm)
All	0.016 (0.40)
Fastening Devices:	Same as stainless steel
Vessels, Tanks, Flat Surfaces	Thickness, in.
Deep corrugated or profiled sheets (1-¼-, 2-½-, 4-in. box, etc.)	
Curved and flat surfaces	0.016 (0.40)
Fastening Devices:	Same as stainless steel Combination metal and neoprene washers on any of the screws may be desirable for better seal. (See Note 1) Screw sizes and lengths are minimums.

[A] Coatings can be aluzinc, aluminized steel or galvanized.

8.3.3.1 *Advantages*—It is tough, chemically resistant, weather resistant, and available in colors.

8.3.3.2 *Limitations*—It is difficult to use on small diameter pipe because it is difficult to bend the material sufficiently to meet the radius of curvature. FRP can be made in preformed shapes such as 90° ell covers and tees. With special shapes for rain shields, head covers can be prefabricated to reduce labor in the field. 90° ells are made in one piece in all sizes to allow quick installation and a moisture-proof cover. Cutouts can be made in the field and sealed with resin or caulk.

8.3.3.3 *Application*—FRP ell covers are opened and placed over the insulation. The throat is sealed with silicone caulking and a band is placed around the cover. FRP raw material components can be field applied.

8.3.4 *Rubberized Bitumen or Butyl Rubber/Polyethylene Jacketing:*

8.3.4.1 This type of material can be used for the protection of both hot and cold insulated piping on above and below ambient systems. It is also used as a vapor retardant on above and below ground cold systems.

8.3.4.2 This type of jacketing is either shop or field applied. It is mostly applied using a self-adhering surface system.

8.3.4.3 Speed of application and no cleanup are major advantages. A common feature of nonmetallic jackets is the reduction of personal injury cuts to insulators and other trades, especially versus stainless.

8.3.4.4 On large tanks, it is difficult to keep wrinkles out of this jacketing. Laminated jackets can be preapplied to insulation by the manufacturer or in a shop requiring only that the lap be closed in the field to reduce labor.

8.3.5 *Laminated Composites:*

8.3.5.1 Laminations using fluoropolymer film laminated to a chlorosulfonated polyethylene-based synthetic rubber-coated glass fabric for high surface temperature (450°F (232.2°C)) applications. This material is recommended because it has very good resistance to ultraviolet (UV), caustics, and acids and has good abrasion resistance. These laminations allow the insulation to breathe and at the same time keep moisture out. They do not crack and dent like metal and mastics.

8.3.5.2 These laminated jackets are cut to size on-site or in a shop and, on hot applications, are attached with outward clinching SS staples and the joints sealed with pressure-sensitive tape made from fluoropolymer film. For vapor retarder jackets, the overlaps should be sealed with adhesive and taped with a vapor retarder pressure-sensitive tape to create a complete vapor seal.

8.3.6 Commonly used nonmetallic protective jacketing and thicknesses are shown in Table 9.

8.4 *Vapor Retarders:*

8.4.1 Vapor retarders are generally applied to mineral fiber or foam insulation as a vapor retarding finish for low abuse

TABLE 9 Commonly Used Nonmetallic[A] Protective Jacketing[B] and Thicknesses

Description	Thickness, inches (mm)
CPVC; Chlorinated PolyVinylChloride -UV resistant	0.020-0.050 (0.50-1.27)
Laminate Jacketing, Specification C1775	0.007-0.0018 (0.18-0.46)
PVC; PolyVinylChloride	0.020-0.30 (0.51-7.62)
PVC low smoke	0.020-0.30 (0.51-7.62)
PVF; PolyVinylFlouride/scrim/ synthetic rubber	0.010-0.15 (0.25-3.81)
Rubberized bitumen/plastic film	0.050-0.125 (1.27-3.18)
Silicone-impregnated glass fabric	0.014-0.037 (0.36-0.93)
GRP; Glass Reinforced Plastic	0.060-0.080 (1.5-2.0)

[A] Products are not made of sheet metal, but may contain an aluminum foil component.
[B] Some protective jacketing can also serve as a vapor retarder if properly sealed. Consult manufacturer's technical data.

areas or as an inner vapor retarding membrane to be covered with another jacket for high abuse areas or for exterior use.

8.4.1.1 Vapor retarders for mineral fiber insulation are typically applied in the factory that produces the insulation material. Vapor retarders for foam insulation are commonly applied to the insulation in a fabrication shop, but can be applied in the field.

8.4.1.2 For pipe, these products are usually supplied with a self-sealing lap system, for the longitudinal seam, or adhesive or adhesive tapes will be manually applied to the longitudinal lap in the field. Circumferential butt strip tape is applied at the job site. If a vapor retarder is not required, the longitudinal lap joint may be stapled closed with stainless steel (SS) outward clinching staples on 3 or 4 in. (75 or 10 mm) centers.

8.4.1.3 For flat insulation board, butt joints are typically sealed with tape that matches the vapor retarder.

8.4.1.4 For both pipe and board, joints are typically sealed for aesthetic reasons even if function as a vapor retarder is not critical.

8.4.2 *Plastic Film:*

8.4.2.1 Plastic films of polyvinylidene chloride (PVDC) extruded alone or coextruded with other polymers are used as vapor retarders in cold applications down to cryogenic temperatures. These materials will have a permeance of less than 0.02 perms and will typically be flexible film with thickness of 4 to 6 mils (1.02 to 1.53 mm).

8.4.2.2 In addition to its vapor retarding performance, it is suitable as a protective jacket for indoor scenarios subject to low to moderate physical abuse. This material does not have sufficient UV resistance for use as the outer layer in outdoor use. For outdoor use, it must be protected by an outer, usually metal jacketing.

8.4.2.3 Plastic film vapor retarders are installed, sealed and handled in the same way that laminated materials are. These PVDC films also are available in self-adhesive tape form for use in sealing butt joints and for spiral wrapping around insulation on fittings and elbows.

8.4.3 *Laminations:*

8.4.3.1 Laminated vapor retarders can consist of laminations of various different materials.

8.4.3.2 All-service jacket (ASJ) is the most commonly used lamination and is constructed of either (a) white polymer film, scrim, core material, aluminum foil and fire retardant adhesive, or (b) white kraft paper, tri-directional fiberglass yarn (scrim), aluminum foil, and fire retardant adhesive. The former is employed when it is not desirable to have a paper on the exposed surface, such as below-ambient applications where the potential for surface condensation exists.

8.4.3.3 ASJ is used on pipe and equipment insulation. FSK (Foil-Scrim-Kraft) and PSK (Polymer film-Scrim-Kraft) are sometimes used on equipment in the form of board insulation.

8.4.3.4 PFP (Polyester-Foil-Polyester) uses a 1 mil foil between two layers of polyester film and offers a permeance of 0.00.

8.4.4 *Laminated Composites:*

8.4.4.1 Laminations such as those in 8.3.5 are sometimes used in cold temperature applications

8.4.4.2 Metalized polyester films are added to the inside to give a 0.02 perm rating for cold applications making the lamination a consistent factory controlled vapor retarder.

8.4.4.3 For vapor retarder jackets, the overlaps should be sealed with adhesive and taped with a vapor retarder pressure-sensitive tape to create a complete vapor seal.

8.4.5 Commonly used vapor retarders and permeance values are shown in Table 10.

8.5 *Coating and Sealant Systems:*

8.5.1 The choice of the material used to protect the insulation will be governed by the service, size, shape, and location of the insulated surface to be protected. Materials that cling to the surface by adhesion facilitate the installation of a protective covering to irregular surfaces, which have no ready means of securement.

8.5.2 Mastics may be spray, brush, palm, or trowel applied to surfaces that will not easily accommodate metal jacketing. They may be used in conjunction with metal jacketing in situations such as flashing between two adjacent surfaces or around irregular shapes such as fittings, valves, and so forth since they lend themselves to easy application in these areas.

8.5.3 *Weather Barrier Coatings:*

8.5.3.1 A weather barrier coating trowel, brush, or spray grade is applied to the outer surface of thermal insulation for the primary purpose of protecting the insulation from the weather. It is designed to prevent water (rain, snow, sleet, spillage, wash water, and so forth) from entering the insulation system. The tough flexible films provided by breather coatings (a breather coating is one through which vapors under pressure will pass) also afford protection from mechanical damage, and chemical attack.

8.5.3.2 Mechanical damage can result from external forces in the form of shear, abrasion, impact, or compression that may occur when a sharp object is dropped, when the surface is walked on, or even from extreme weather conditions. Damage may also result from internal forces caused by thermal expansion and contraction, differential movement, or vibration.

8.5.3.3 The use of an appropriate weather barrier can protect the insulation from the chemical attack of acids, alkalis, solvents, and salts either airborne or as a result of intermittent spillage as well as from the effects of oxidation, infrared, and UV radiation. Although breather coatings are used both outdoors and indoors in hot, cold, and dual temperature service, they should be used in cold and dual temperature installations only in conjunction with vapor retarders. When used in hot service, a breather coating allows the escape of a minimal amount of water vapor resulting from heat applied to the

TABLE 10 Commonly Used Vapor Retarders and Permeance Values

Description	Permeance, perms, max.
ASJ (All Service Jacket); film/core/scrim/foil	0.02
ASJ; kraft/scrim/foil	0.02
ASJ; kraft/scrim/metalized polyester	0.02
FSK; Foil/Scrim/Kraft	0.02
PSK; Plastic film/Scrim/Kraft	0.02
PFP; Polyester/1 mil Foil/Polyester	0.00
PVdC; PolyVinylidene Chloride	0.01, 0.02
Rubberized bitumen/plastic film	0.03

moisture entrapped in the insulation, while still preventing the passage of liquid to the insulation.

8.5.3.4 Glass or synthetic fiber cloth such as 10 by 10 (threads/inch), 5 by 5, and other fabric membranes are generally used as reinforcements for weather barriers. In areas subjected to abuse, your heavier cloths like 5 by 5 or stainless steel hex mesh may be used. Coatings used with the smaller mesh like 10 by 10 should never be applied directly over the mesh without a tack coat. This procedure will adversely affect the adhesion of the coating to the insulation.

8.5.3.5 Water-based materials should not be used on flat horizontal surfaces where ponding water might deteriorate the coating. Design should be altered to prevent ponding water or a solvent-based coating should be used.

8.5.3.6 Water-based materials should be protected from freezing during storage and should not be applied when freezing conditions are expected within 24 h of application. Water-based or solvent-based coatings should not be applied at temperatures below 40°F (4.4°C) as they become so viscous you cannot apply them properly. Condensation on the work surface may also hinder adhesion. Solvent-based coatings can withstand freezing but, for best results, should be taken and applied directly from heated storage.

8.5.3.7 Many solvent-based products contain highly flammable solvents, and appropriate precautions should be taken. Solvent vapors in fairly low concentrations can cause narcosis; therefore, adequate ventilation should be ensured whenever solvent-based materials are applied. MSDS should be referred to for proper information and precautions.

8.5.3.8 Special attention should be given to any area in which the coating will come into direct contact with the piping or equipment surface. Follow manufacturer's or owner's recommendations or both for finishing these areas.

8.5.3.9 Solvent-free materials, such as epoxies or urethanes, may be specified when particular chemical resistance or other properties are necessary.

8.5.3.10 All coatings should be applied only on thoroughly dry insulation materials, especially insulating and finishing cements. Dusty insulation surfaces need to be primed per manufacturers' recommendations for maximum adhesion.

8.5.4 *Vapor-Retardant Coatings:*

8.5.4.1 In cold or dual temperature service, the equipment is operating below ambient temperature at least part of the time. Water vapor in the air moves from the area of high vapor pressure (ambient temperature) to the area of low pressure (the low-temperature equipment). As the vapor passes through or around (at joints) the insulation, the closer it comes to the low-temperature equipment or piping the colder it becomes. At some point, the water vapor reaches its dew point temperature and condenses to liquid reducing the efficiency of the permeable insulation. Closer to the cold surface, if the temperature is low enough, the liquid may freeze and destroy the value of the insulation. In dual temperature service, alternate freezing and thawing of the moisture in the insulation may actually physically destroy the insulation.

8.5.4.2 Good vapor-retardant coatings are formulated to afford maximum protection from mechanical damage, chemical attack, while at the same time preventing the passage of vapor to the insulation. These products, whether brushed, palmed, or sprayed, are normally applied with a fabric-reinforcing membrane such as 10-by-10, 10-by-20, or 5-by-5 mesh. The 5-by-5 wrap & weave mesh is used where additional mechanical strength is needed.

8.5.4.3 Water-based vapor-retardant coatings should not be used on surfaces that will remain wet for long periods of time. Caution should be exercised in making sure the vapor-retardant coating is compatible with joint sealants and insulation adhesives (especially asphalt) used under it.

8.5.4.4 It is essential that the vapor-retardant coating not be used as the exposed finish if it is likely to be damaged during service. The number one contributor to coatings failure to date has been application of improper coating thickness. It should be a high priority of those involved to assure that these coatings are applied with the correct number of coats and the total dried film thickness as specified from the specification or the data sheet from the manufacturer.

8.5.4.5 Commonly used coatings and thicknesses are shown in Table 11.

8.5.5 *Metal Jacketing Joint Sealants:*

8.5.5.1 *Hot Applications*—The use of sealants (sometimes called flashing sealant or flashing adhesive) at the longitudinal and butt joints of metal jacketing on hot applications is a practice which is controversial. Some system designers specify the use of sealant at these locations as an added barrier to keep liquid water out of the insulation system. Other system designers prohibit the use of sealant on the metal jacketing under the reasoning that a perfect seal of metal jacketing is not possible so liquid water will inevitably enter and the metal jacketing joints must be left unsealed to best allow for evaporation of this water. These two competing system designs and their associated theories have not been studied nor has the lifespan of insulation systems using these competing designs been studied so there remains at this time no definitive design advice that can be given on the use of metal jacketing joint sealants in hot applications. The system designer should give credence to the metal jacketing manufacturer's recommendations when deciding whether sealant should be used on the metal jacketing joints in hot insulation systems.

8.5.5.2 *Cold Applications*—The impact of using or not using metal jacketing joint sealants at the longitudinal and butt joints of metal jacketing on cold applications has also not been studied. In cold applications, the presence of a vapor retarder should prevent or, at least, minimize the intrusion of water into the insulation material. Any water which penetrates the metal

TABLE 11 Commonly Used Coatings, Thicknesses

Weather Barriers	Thickness, inch (mm)
Polyvinyl acetates emulsions	0.058 (1.47) - 0.063 (1.6) dry film thickness (DFT)
Asphalt emulsions	0.080 (2.0) - 0.125 (3.175) DFT
Asphalt cutbacks	0.0625 (1.5) - 0.125 (3.175) DFT
Synthetic rubbers	0.030 (0.76) - 0.063 (1.6) DFT
Epoxies	
Vapor Retardants	Thickness, in.
Asphalt cutbacks	0.0625 (1.5) - 0.125 (3.1758) DFT
Synthetic rubbers	0.030 (0.76) - 0.063 (1.6) DFT
Copolymer emulsion	0.038 (0.90) - 0.057 (1.45) DFT

jacketing would remain primarily in the space between the vapor retarder and the metal jacketing. While this will have less of an impact on the performance of the insulation material, it could lead to a greater propensity for corrosion of the interior surface of the metal jacketing. As with hot applications, no definitive design advice that can be given on the use of metal jacketing joint sealants for cold applications. The system designer should give credence to the metal jacketing manufacturer's recommendations when deciding whether sealant should be used on the metal jacketing joints in cold insulation systems.

8.5.5.3 When metal jacketing joint sealant is used, it shall be vapor retarder type, moisture and water resistant, exhibit low shrinkage during cure, be non-hardening, and remain flexible with a service temperature range from -40°F to 250°F (-40°C to 121°C). Jacketing sealant shall be applied in the jacketing joint between the overlapping pieces of metal and not as a bead of caulk on the exterior lip of the jacketing joint. Jacketing sealant shall be applied before closing and banding of the jacketing. Butyl elastomer based sealants are one type that has been used in this application and which adheres well to both the metal and the moisture barrier which may be on the interior surface of the metal jacketing.

8.5.6 *Requirements of the Coating and Sealant System:*

8.5.6.1 There are presently many governmental and private industry specifications dealing with specific requirements. These specifications include consideration of:

8.5.6.2 *Solvent- or water-based system*—Care should be taken so that the system will not attack the substrate to which it is applied. It should dry in the time required and under the conditions to which it will be exposed.

8.5.6.3 *Toxicity*—What is the threshold limit of each ingredient, and what steps should be taken to prevent exceeding the level?

8.5.6.4 What is the flammability of the system (in the wet state) and will it create an undesirable hazard?

8.5.6.5 What is the fire performance of the dry film and will it meet all the necessary requirements?

8.5.6.6 Has the material been tested for flame spread index and smoke developed index in accordance with Test Method E84 (which assesses surface burning characteristics of building materials)? Make sure the material was tested, with any applicable adhesive and facing at the recommended and installed total thickness.

8.5.6.7 What is the resistance of the various mechanical factors such as expansion and contraction, vibration, shear, abrasion, impact, and compression?

8.5.6.8 What thermal factors such as application temperature limits, freeze thaw stability, and service temperature requirements need to be considered?

8.5.6.9 What are the chemical resistance factors of the system to acids, alkalis, and solvents?

8.5.6.10 Is the material best applied by trowel, palm, brush, or spray?

8.5.6.11 What is the recommended dry film thickness of the specified product? Test data on the physical properties of any product are generated based upon a specific dry film thickness. Too much, as well as too little, coverage can dramatically affect the performance of a product.

8.6 For all protective jacketing, vapor retarders, coating and sealants, manufacturer guidelines should be consulted to confirm suitability for intended use and to insure proper installation, prior to commencing work. Workmanship is especially critical in assuring adequate vapor-retarding performance on below-ambient systems.

9. Guarantees

9.1 *General:*

9.1.1 Bid invitations should contain information necessary to determine how guarantees of materials and application will be resolved.

9.1.2 Any failure of the finished system to comply with the specification requirements should be corrected by the contractor at the contractor's expense.

9.2 *Payment*—The inquiry from the purchaser should state any intention to retain an agreed percentage of the total value of the work for an agreed period after the work has been completed.

10. Inspection, Testing, and Maintenance

10.1 *General:*

10.1.1 It is recommended that the purchaser provide a quality assurance program that defines the inspection of all materials, MSDS sheets, and specific application procedures before and during progress of the insulation work. The purchaser or his inspection authority should have free access at all reasonable times to those parts of the sites carrying out the work for the specific contract. The purchaser should be allowed to select samples from the materials to be applied and reject any materials or workmanship that does not conform to the relevant specification and contract documents. The purchaser may perform acceptance tests to his satisfaction.

10.1.2 Approval by the purchaser, his inspection authority, or a waiver of inspection should not relieve the contractor of his responsibilities for the design, materials, or workmanship. The contractor should cooperate and provide the opportunity for this inspection to be carried out.

10.1.3 Finishing materials should also be inspected for quality and thickness either before or during application, dependent upon the particular type of finish used.

10.1.4 It is preferable that inspection should be carried out as each stage of work is completed and before the next stage is started. The contractor should give the purchaser or his inspection authority adequate notice of stage of completion to avoid disruption and maintain continuity of work.

10.1.5 The site organization of the contractor should be such that there is a regular and systematic supervision of the work by experienced competent staff.

10.1.6 Until final acceptance of the installation by purchaser, the contractor should make good any damage to insulation at his own expense, unless predetermined extraneous conditions are contractually identified, so that installation is handed over in a perfect condition.

10.1.7 For the purpose of inspecting insulated surfaces, a removable section insulation or inspection port should be considered.

10.2 *Insulation Quality Assurance Procedure*—This general instruction covers the minimum quality assurance/quality control (QA/QC) procedures to be used for thermal insulation practices. Specific instructions for special applications should be followed.

10.2.1 Underground granular pourable insulation should be inspected to the extent necessary to ensure the entire pipeline has been insulated per site specification requirements.

10.2.2 Work performed should be monitored as necessary to ensure design requirements are satisfied. Personnel should meet site requirements to be qualified as inspectors.

10.3 *Insulation Supervisor Responsibilities:*

10.3.1 Ensure that correct material is used and complies with specification, procedures, and drawings.

10.3.2 Ensure surfaces to be insulated are prepared, cleaned, and insulated per owner specifications.

10.3.3 Ensure all deviations from specifications are authorized by controlling design engineer and documented in the project records.

10.4 *QA Inspector Responsibilities:*

10.4.1 Perform in-process inspections of work performed to ensure applicable specifications are followed.

10.4.2 Document acceptable inspection results on the "Insulation Inspection Checklist" (Appendix X1).

10.5 *In-Process Inspection:*

10.5.1 Insulation inspection should include the following:

10.5.1.1 Verify that specified insulation material is used and application procedures are followed;

10.5.1.2 Check the surface condition before insulating;

10.5.1.3 Inspect insulation materials for proper type, thickness, and condition;

10.5.1.4 Inspect for dryness;

10.5.1.5 Visually inspect insulated surfaces for corrosion protection;

10.5.1.6 Inspect joints for tight fits and seals;

10.5.1.7 Mastic finish is holiday and pin hold free on mastic finishes.

10.6 *Documentation:*

10.6.1 In-process inspections will be documented on the Insulation Inspection Checklist.

10.6.2 Pipe fabrications to be insulated in the shop will be inspected and documented on the Insulation Inspection Checklist.

10.6.3 Installed piping to be insulated in the field will be inspected and documented on the Insulation Inspection Checklist.

10.6.4 Equipment to be insulated in the field will be inspected and documented on the Insulation Inspection Checklist. (This checklist will be given to the Inspector Supervisor and will be retained in the applicable project QA file documentation.)

10.7 *Insulation Inspection Checklist*—See Appendix X1.

11. Maintenance Recommendations

11.1 *General:*

11.1.1 During contract negotiations, the contractor and purchaser should discuss and agree to the procedures to be adopted for suitable periodic inspection and maintenance of the insulation systems to ensure that the initial performance of the material will be maintained and, where applicable, agree to the methods of repair and replacement to be adopted should damage occur during service or overhaul.

11.1.2 Inspection of the external surface should include signs of cracking, distortion, damage, corrosion, evidence of hot spots on high-temperature systems, or condensation or ice buildup on low-temperature systems. When necessary, external finish should be removed to enable inspection of the insulation and attachments. Suitable remedial treatment should be carried out to avoid further deterioration of the insulation system. To assist routine inspection of insulation in service, nondestructive testing (NDT) methods, such as thermal imaging or flash radiography, may be considered.

11.1.3 The purchaser should ensure that only qualified personnel are employed for the dismantling of existing insulation and the re-insulating process when repairs or modifications are to be made.

11.2 *Inspection, Maintenance, and Sealing of Insulation Containing Asbestos:*

11.2.1 It is essential that all asbestos-containing materials (ACM) be inspected, identified, and maintained to ensure that the surface condition remains sound, undamaged, and free from loose fiber. Where there is risk of abrasion or physical damage, a program of preventative action should be established. This program should take into consideration the three main types of asbestos abatement: enclose, encapsulate, or removal.

11.2.2 When establishing an asbestos control program, the procedures should satisfy the requirements of the Environmental Protection Agency (EPA), The Occupational Safety and Health Administration (OSHA), state, and local requirements. It is the responsibility of the owner of the ACM to insure that personnel responsible for the maintenance of the ACM be qualified and certified to perform their assigned function.

12. Keywords

12.1 industrial thermal insulation; insulation system; thermal insulation

APPENDIX

(Nonmandatory Information)

X1. INSULATION INSPECTION CHECKLIST

Contractor: ____________________________ Contact: ____________________________

Project: ________________________ Area: ____________________________

Location: ____________________________ Date: ____________________________

Dwg with Rev #: ____________________________ Line/Sketch #: ____________________________

Scope: ____

Insp. Acceptable Date Initials: ____________________________

1. Insulation stored properly
____
2. Correct insulation material and thickness
____
3. Corrosion protection (when required by specification)
____
4. Substrate painted (when required by specification)
____
5. Steam tracer connections are on outside of the insulation
____
6. Insulation fittings correct size, thickness, type
____
7. Insulation joints staggered correctly
____
8. Insulation properly fitted
____
9. Insulation properly secured
____
10. Pipe and equip. properly finished, caulked, sealed, watershed, etc.
____

Other:
____
____

Remarks:
____
____

Signature (Inspector Acceptance): ____________________________ Date: ____________________________

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