PIP INEG1000
Insulation Design Guide
PURPOSE AND USE OF PROCESS INDUSTRY PRACTICES

In an effort to minimize the cost of process industry facilities, this Practice has been prepared from the technical requirements in the existing standards of major industrial users, contractors, or standards organizations. By harmonizing these technical requirements into a single set of Practices, administrative, application, and engineering costs to both the purchaser and the manufacturer should be reduced. While this Practice is expected to incorporate the majority of requirements of most users, individual applications may involve requirements that will be appended to and take precedence over this Practice. Determinations concerning fitness for purpose and particular matters or application of the Practice to particular project or engineering situations should not be made solely on information contained in these materials. The use of trade names from time to time should not be viewed as an expression of preference but rather recognized as normal usage in the trade. Other brands having the same specifications are equally correct and may be substituted for those named. All Practices or guidelines are intended to be consistent with applicable laws and regulations including OSHA requirements. To the extent these Practices or guidelines should conflict with OSHA or other applicable laws or regulations, such laws or regulations must be followed. Consult an appropriate professional before applying or acting on any material contained in or suggested by the Practice.

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# PIP INEG1000
## Insulation Design Guide

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### Data Forms

- **INEG1000-D001** – Documentation Requirements Sheet
  
  *The following data forms shall be part of this Practice only if indicated on the purchaser’s completed Documentation Requirements Sheet.*

- **INEG1000-D002** – Hot Service Insulation Design Parameters

- **INEG1000-D003** – Cold Service Insulation Design Parameters
1. **Scope**

This Practice provides guidance for the design of insulation systems. This Practice describes the types of insulation systems that are indicated by the type code on the Piping and Instrumentation Diagrams (P&IDs), data sheets, and other design documents. This Practice provides guidance on insulation design criteria, insulation materials, extent of insulation, determination of insulation thickness, and insulation material properties.

2. **References**

Applicable parts of the following Practices, industry codes and standards, and references shall be considered an integral part of this Practice. The edition in effect on the date of contract award shall be used, except as otherwise noted. Short titles will be used herein where appropriate.

2.1 **Process Industry Practices (PIP)**

- PIP CTSE1000 – *Application of External Coatings*
- PIP INSC1000 – *Cold Service Insulation Materials and Installation Specification*
- PIP INSH1000 – *Hot Service Insulation Materials and Installation Specification*
- PIP INSR1000 – *Installation of Flexible, Removable/Reusable Insulation Covers for Hot Insulation Service*

2.2 **Industry Codes and Standards**

- American Petroleum Institute (API)
  - API RP521 – *Guide for Pressure-Relieving and Depressuring Systems*
  - API RP2001 – *Fire Protection in Refineries*
  - API PUBL 2218 – *Fireproofing Practices in Petroleum and Petrochemical Processing Plants*

- American Society of Testing and Materials (ASTM)
  - ASTM C240 – *Standard Test Methods of Testing Cellular Glass Insulation Block*
  - ASTM C547 – *Standard Specification for Mineral Fiber Pipe Insulation*
  - ASTM C552 – *Standard Specification for Cellular Glass Thermal Insulation*
  - ASTM C680 – *Standard Practice for Determination of Heat Gain or Loss and the Surfaces Temperatures of Insulated Pipe and Equipment Systems by the Use of a Computer Program*
  - ASTM C800 – *Standard Specification for Glass Fiber Blanket Insulation (Aircraft Type)*
  - ASTM C871 – *Standard Test Methods for Chemical Analysis of Thermal Insulation Materials for Leachable Chloride, Fluoride, Silicate, and Sodium Ions*
  - ASTM C1055 – *Heated System Surface Conditions That Produce Contact Burn Injuries*
  - ASTM C1104 – *Standard Test Method for Determining the Water Vapor Sorption of Unfaced Mineral Fiber Insulation*
  - ASTM E96 – *Standard Test Methods for Water Vapor Transmission of Materials*

2.3 Other References

• Federal Energy Administration Report

• National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce – www.noaa.gov

• North American Insulation Manufacturers Association (NAIMA) – 3E Plus

3. Insulation Materials

3.1 Categories

Insulation materials fall into the following three major generic categories based on the structure of the insulation material and each has properties that give it unique performance characteristics:

a. Closed cell
b. Fibrous
c. Granular

3.2 Closed-Cell Insulations

3.2.1 Closed-cell insulations include:

a. Cellular glass
b. Various organic materials such as rigid polymer foams, polyisocyanurate, polyurethane, and polystyrene
c. Elastomeric foams

3.2.2 The closed-cell structure of these materials provides a natural resistance to absorption and permeation by external water and water vapor as well as to absorption of leaking process chemicals. Closed-cell insulations are typically chosen for low-temperature applications in which control of moisture penetration is important. ASTM E96 is a test method for water vapor permeability that can be applied to all insulation materials. ASTM C240 is a water absorption test method that is published for cellular glass. Some insulation manufacturers test their materials using both of these procedures and publish the results in their product literature. For both test methods, the lower the value, the more resistant the material is to absorption and permeability.

3.2.3 The upper-use temperature of the rigid polymers and elastomeric foams is limited, and the manufacturer’s recommended maximum temperature should be followed. Cellular glass is made from inorganic material that gives a wider, usable temperature range and applicability in elevated temperature service in which absorption resistance is needed.

3.2.4 In applications below ambient, most of these materials should be used with a separate vapor barrier and with a weather-proof jacket. All outer-layer joints should be sealed.
using the insulation manufacturer’s recommended material in any application in which condensation could occur on the insulated pipe or equipment. All the closed-cell materials can be used for condensation control and cold conservation.

3.2.5 While the rigid foams and cellular glass have some strength, damage resistance is not necessarily provided. The elastomeric foams are resilient and should resist light physical abuse.

3.2.6 If exposed to ultraviolet (UV) light for extended periods of time, the properties of most of the organic materials deteriorate. If using organic closed-cell materials in an exterior application, a UV-protective finish should be used.

3.3 Fibrous Insulations

3.3.1 Fibrous insulations include:
   a. Fiberglass
   b. Mineral fiber
   c. Needled E glass
   d. Ceramic fiber
   e. Flexible Aerogel

3.3.2 The fundamental difference between the fibrous insulations is the raw material from which they are made. Mineral fiber is made from volcanic rock; fiberglass and E glass are made from inorganic glass fibers; and ceramic fibers are made from inorganic ceramics.

3.3.3 Fibrous insulation is not resistant to moisture permeation and can absorb water or chemicals if exposed to liquid or vapor. There is no permeation minimum included in the ASTM standards for any of the fibrous materials. For this reason, fibrous insulation is not used alone for low-temperature applications in which condensation can occur. If used at an elevated temperature, the organic binder that helps to hold the insulation together is burned away causing a reduction in strength and an increase in the ability to absorb moisture.

3.3.4 The fibrous insulations, depending on form, are somewhat flexible and have little compressive strength. As a result, piping should not be supported through fibrous insulation, and higher strength materials should be considered in damage-prone areas.

3.3.5 The fibrous insulations do not burn but do absorb flammable chemicals that can burn. In cases in which leaking flammables are likely, the fibrous materials should not be used.

3.3.6 Flexible aerogel material may be composed of amorphous silica or be fibrous in nature, and may exhibit different performance properties than what is listed above for fibrous materials.

3.4 Granular Insulations

3.4.1 Granular insulations include perlite and calcium silicate because of composition from a starting material that is granular in form.

3.4.2 Granular insulations have much higher density and compression strength than most fibrous and closed-cell materials. Because of the higher strength, the insulations can be used to support piping loads and to resist damage.
3.4.3 Calcium silicate is highly absorbent and should not be used if direct exposure to moisture or leaking chemicals is likely. At temperatures below 500°F (260°C), perlite resists moisture absorption and may be used if corrosion under insulation is a concern; however, perlite is not typically used in low-temperature applications. At temperatures above 500°F (260°C), the organic binder that imparts the moisture resistance is no longer effective, and moisture absorption is possible.

3.5 Jacket Materials and Accessories

3.5.1 The jacket is a key part of an insulation system. The primary function of the jacket is to protect the insulation material from the elements, especially water and external mechanical abuse.

3.5.2 Aluminum Jacketing

3.5.2.1 Typically, aluminum jacket material is used in chemical and petrochemical plant applications. The aluminum materials are available in several thicknesses and finishes depending on the application. The two major aluminum finishes are stucco-embossed and smooth. Stucco-embossed aluminum has a rough finish that is rolled into the sheet metal during manufacture. The benefit of this finish is that minor surface damage is less visible. Owners prefer the appearance of the smooth jacket rather than stucco embossed because of appearance and ease of cleaning.

3.5.2.2 Increasing the thickness and adding corrugations improves the damage resistance of both materials. Corrugations increase the bending strength perpendicular to the axis of the corrugations.

3.5.2.3 Corrugated jackets should not be used on horizontal surfaces if the corrugations are oriented parallel to the horizontal axis, because water can be held in the troughs formed by the corrugations on the top surface. This water can run to the joints in the jacket and enter the insulation.

3.5.2.4 Aluminum has excellent weathering characteristics if exposed to normal industrial atmospheres. There are specific chemicals such as caustics and chloride salts that can damage aluminum and aluminum should not be used if directly exposed to these chemicals. If chemical exposure is likely, a corrosion specialist should be consulted to determine the appropriate jacket material. Aluminum jacket can be obtained with a coating to provide added chemical resistance, color-coding, or increased emissivity.

3.5.3 Other Jacket Materials

3.5.3.1 Other common jacket materials are stainless steel, zinc-aluminum alloy-coated steel, and PVC.

3.5.3.2 Stainless Steel Jacketing

1. Stainless steel jacketing is used if fire resistance is needed. Stainless steel has a much higher melting point than aluminum and remains intact much longer during an external fire than aluminum. The higher melting point permits the use of smaller relief devices on insulated pressure equipment and provides protection for both the equipment and insulation.
2. Chemical resistance is also an important benefit of stainless steel and can be used in areas where chemical fumes or spills are a problem that aluminum cannot resist.

3. Stainless steel is stronger and heavier than aluminum, which permits use in thinner sheets. The added strength improves damage resistance in comparison to aluminum.

**3.5.3.3 Zinc Aluminum Alloy-Coated Steel Jacketing**

1. Zinc aluminum alloy-coated steel jacketing also is used if mechanical strength or fire protection is needed.

2. Zinc aluminum alloy-coated jacketing should not be used on stainless steel pipe and equipment because of the risk of zinc embrittlement of the stainless steel in the event of a fire. Zinc embrittlement occurs if the zinc coating melts and the liquid zinc makes contact with austenitic stainless steel. The liquid zinc penetrates the stainless steel and causes cracking. Welds are especially vulnerable to this type of cracking.

**3.5.3.4 Nonmetallic Jacketing**

1. Nonmetallic jackets are also typically used. White PVC is used in outdoor applications or if cleanliness is important. PVC is also available in a variety of colors if the jacket is to be color-coded, however, colored PVC should not be used outdoors.

2. Complicated shapes can be handled by fabricating the jacket in place using mastic and reinforcing fabric. This approach is often used in combination with metal jacket in which the metal is used for the straight sections, and the mastic is used for the complicated shapes. Metal fittings should be used for tees and elbows for PIP installations.

**3.5.4 Accessories**

- **3.5.4.1** Non-metallic accessories (i.e. cements, mastics, adhesives, tapes, etc.) are selected based on insulation material and system configuration.

- **3.5.4.2** Metallic accessories (i.e. springs, bands, seals, screws, etc.) shall be stainless steel.

**3.6 Vapor Barriers**

- **3.6.1** Insulation systems that operate below the ambient dew point temperature should be protected from the inward permeation of moisture. Water vapor permeability is measured using ASTM test method E96, and the results are reported in “perms.” Lower perm ratings represent better resistance to moisture penetration. Closed-cell insulation materials have low perm ratings, while fibrous and granular materials are typically not evaluated for permeation. Because of the low perm rating, closed-cell materials are used for low-temperature applications.

- **3.6.2** As an added measure of resistance against moisture penetration, an additional vapor barrier is added to the outer surface of the insulation. The vapor barrier can be sheet material or vapor barrier mastic that is applied to the outside surface of the insulation. Nonsetting joint sealer is used to seal the joints of single-layer insulation and the outer layer of multilayer systems.
4. Insulation System Design

4.1 General

4.1.1 An insulation system consists of the insulation material, protective covering if needed, and accessories used to secure the insulation in place.

4.1.2 The insulation materials chosen depend upon the reasons that insulation is being used. Many different criteria are important in the selection of an insulation system. Not all the criteria mentioned in this Practice apply in all cases. The criteria that apply to a project should be determined, and priorities should be assigned to those criteria. In some cases, it may be that only heat conservation or personnel protection are important. In most projects, many criteria apply with some being much more important than others. Because each project is unique, the criteria should be assessed for each project, and selections should be made that are appropriate to their unique circumstances. Design criteria that should be considered in the selection of insulation materials are described in Section 4.2 of this Practice.

4.2 Basic Design Criteria

4.2.1 The primary reason for using insulation should be established first. Possible reasons are:
   a. Heat conservation
   b. Personnel protection
   c. Process stability
   d. Freeze protection
   e. Condensation prevention
   f. Cold conservation
   g. Acoustic control
   h. Fire-protection

   The possible reasons are aligned with the PIP type codes that are used on P&IDs to designate the insulation type.

4.2.2 Heat Conservation Insulation

4.2.2.1 Heat conservation (HC) insulation is applied to prevent the escape of thermal energy from process equipment and piping. An optimum thickness can be determined that balances the cost of installing and maintaining the insulation system against the value of the energy saved. This thickness is referred to as the “economic thickness” and can also be defined as the insulation thickness that yields the minimum total cost of owning insulation.

4.2.2.2 Calculation of the economic thickness depends on many variables and should be determined on a case-by-case basis. The National Association of Insulation Manufacturers (NAIMA) has published software (3E Plus) that can be used to calculate economic thickness. 3E Plus uses heat transfer calculations that are based on ASTM C680 and economic thickness calculations based on the Federal Energy Administration Report, Economic Thickness for Industrial Insulation.
defined as the sum of the cost of the insulation system materials plus the cost of
the energy lost minus any tax savings.

4.2.2.3 Energy loss is reduced for a given insulation material by increasing the
insulation thickness. Increasing the thickness raises the cost of the insulation but
lowers the cost of lost energy. At the economic thickness, the cost of adding
additional insulation thickness is greater than the value of the additional energy
saved.

4.2.2.4 The calculations made to determine the economic thickness require the input of
project-specific data on process conditions, ambient conditions, and economic
data that is specific to the project. To determine an accurate economic thickness,
this data should be obtained for each project. The software contains default
values for process, ambient, and economic variables. However, the default
values are subject to variation and can cause inaccurate economic thickness
calculations.

4.2.3 Personnel Protection Insulation

4.2.3.1 Personnel protection (PP) insulation is used to prevent contact between
personnel and hot operating surfaces. The maximum allowable insulation system
surface temperature is 140°F (60°C) for metallic surfaces. Higher allowable
surface temperatures may be appropriate for non-metallic surfaces, as indicated
in ASTM C1055 Appendix for materials with lower thermal inertia.

4.2.3.2 ASTM C1055 establishes a process for the determination of acceptable surface
operating conditions for heated systems. ASTM C1055 also defines human burn
hazards and presents methods for use in the design and evaluation of heated
systems to prevent serious injury from contact with exposed surfaces. The
method establishes a safe surface contact temperature based on an acceptable
contact time and level of injury. A graph is included in ASTM C1055 that
establishes the temperature-time relationship for burns of specific severity. For
the purposes of this Practice, the acceptable level of injury is reversible
epidermal injury as defined in ASTM C1055, and the PIP adopted acceptable
contact time is 2 seconds. Using the ASTM C1055 graph and the injury and time
parameters leads to the PIP maximum allowable surface temperature of 140°F
(60°C). This temperature is used to calculate the personnel protection thickness.
The personnel protection thickness is chosen so that the outside surface
temperature of the insulation system is no more than 140°F (60°C) for metallic
surfaces under the worst-case operating conditions of highest operating
temperature combined with the highest expected ambient temperature.

4.2.3.3 Two very important variables in the calculation of outside surface temperature
are the emissivity of the jacket material and the wind speed. As the wind speed
increases, the surface temperature falls significantly because of convective
cooling. The wind speed for indoor applications is low, resulting in higher
personnel protection thicknesses than for the same system in an outdoor location.
Choosing a jacket material with high emissivity also reduces the surface
temperature and is a method that can be used to lower the personnel protection
thickness for indoor applications or for high temperature outdoor installations.
As the process temperature drops, increasing the emissivity becomes less
effective at lowering the surface temperature.
4.2.3.4 3E Plus or an equivalent program can be used to calculate the personnel protection thickness.

4.2.4 Process Stability Insulation

Process stability (PS) insulation is used to maintain the process temperature at a desired level. The amount of heat loss or heat gain permitted for a process depends on the nature of the process. 3E Plus can be used to calculate both heat loss and heat gain through insulation as a function of insulation type and process conditions.

4.2.5 Prevention from Freezing Insulation

4.2.5.1 Prevention from freezing (PF) insulation is used to prevent water or process fluid piping from freezing without using supplemental heat input (either electric or steam). The system design requires consideration of all potential heat leak paths, such as pipe supports and terminations at enclosures. These heat leak paths can result in localized ice formation and line plugging.

4.2.5.2 Insulation can be designed to prevent the contents of a pipe or vessel from freezing when ambient temperatures fall below the freeze point temperature of the insulated liquid. 3E Plus is not used to calculate the required thickness but can be used to calculate the heat loss rate (heat flux) from an uninsulated surface as well as through a range of insulation thicknesses. The important variables in making this calculation are ambient temperature and wind speed. If the heat flux is known it can be used to calculate the time required for the process fluid to freeze. The volume, heat capacity and heat of fusion of the fluid are needed to calculate the amount of energy that can be lost and the length of time required for freezing to occur. Flow through the item to be insulated greatly complicates the calculation. Local freezing could occur faster or slower as a result of attachments to the insulated item. The insulation thickness is selected to provide a specified time before freezing occurs.

4.2.5.3 Caution should be exercised when calculating time to freeze since slush can form before then and plug orifices and strainers. This insulation approach should not be used where freezing conditions over multiple days occur on a regular basis, or the service is critical to process control or plant operation.

4.2.6 Cold Service Insulation

4.2.6.1 Cold service insulation (CC) is primarily intended to limit heat gain by the process. The allowable heat gain should be determined for each process. The required insulation thickness is determined based on the local worst-case ambient conditions. In most cases, the thickness should also be sufficient to keep the surface temperature of the jacket material above the ambient dew point temperature to prevent condensation on the jacket surface. 3E Plus can be used to calculate heat gain, dew point, and surface temperature.

4.2.6.2 The control of moisture penetration in low-temperature systems is required to prevent condensation or the formation of ice inside the insulation and on the surface of the insulated item. This control is accomplished by designing an insulation system that includes a closed-cell insulation material, a vapor barrier with a low permeation rating as determined by ASTM E96, and an appropriate jacket with moisture resistant caulking at all joints and penetrations. Non-closed
cell insulation does not resist moisture penetration and is prone to moisture absorption if the vapor barrier seal is broken. This insulation should not be used if the operating temperature is below the highest expected ambient dew point. In dual-temperature applications, fibrous material can be used as an inner layer to compensate for thermal expansion, but it should be covered by a closed-cell outer layer and vapor barrier system to prevent condensation or ice formation on the inner surface.

4.2.7 Condensation Prevention Insulation

Condensation prevention (CP) insulation is used only to prevent condensation from occurring on the surface of piping and equipment that is operating at or below the ambient dew point. The design of condensation prevention systems is the same as cold service insulation. Thickness is designed only to raise the surface temperature above the project design ambient dew point. Condensation prevention is typically important for housekeeping, safety and corrosion control. Closed-cell insulation materials should be used in condensation control applications. 3E Plus can be used to determine the required thickness.

4.2.8 Acoustic Control Insulation

4.2.8.1 The primary consideration for use of acoustic control insulation (AC) should be control of noise.

4.2.8.2 Typically, acoustic control insulation should have a dedicated design for each application. Refer to ISO 15665 for additional information on acoustic control insulation.

4.2.8.3 Special consideration of insulation materials and jacketing is typically required.

4.2.8.4 Acoustic control insulation can be combined with other types of insulation.

4.2.9 Fire-Protection Insulation

4.2.9.1 The primary consideration for use of fire-protection insulation (FP) should be control of the rate of heat gain in a fire.

4.2.9.2 Design of fire-protection insulation should be based on maximum allowable heat gain, fire case characteristics, allowable time duration, and process characteristics. Refer to API RP 521, API Publication 2218, and API RP 2001 for additional information on fire protective insulation.

4.2.9.3 Fire-protection insulation can be combined with other types of insulation.
4.3 Other Design Criteria

4.3.1 Location of Facilities

The location of the items to be insulated determines the ambient conditions that should be used in calculating the insulation thickness. Location also plays an important role in the choice of accessories such as the jacket type and the method of securement. In high wind areas, band spacing should be reduced to keep the jacket in place. In corrosive areas such as close to the seacoast or corrosive chemical fumes, it may be necessary to select a jacket material that is resistant to the specific corrosive condition. Equipment that is located inside a building is not exposed to weather extremes or UV light and less durable jacket materials, or in some cases no jacket material, can be suitable. Flame spread and smoke developed properties may be important properties depending on location of insulation (e.g. indoor or enclosed) and type of facilities.

4.3.2 Strength and Durability

Physical strength and durability requirements can determine the choice of both insulation and jacket materials. In some cases, pipe support loads are carried by the insulation. In that case, a rigid insulation material is used. Rigid insulation materials can be selected for surfaces that are easily accessible by personnel working on or around the equipment. Jacket materials that are more damage resistant, such as thick aluminum or stainless steel, can be used in conjunction with the rigid insulation to produce a very damage-resistant system.

4.3.3 Appearance

Appearance requirements sometimes determine the type of jacket or finish material that should be used. Applications that require a continuously high degree of cleanliness can specify a jacket material that has a gloss white or polished stainless steel finish to facilitate both identification and removal of surface contamination. Embossed surface finishes on metal jacket materials can be used to make minor surface damage less visible to casual observation; however, it is more difficult to clean embossed jackets. Smooth finishes are more reflective, and damage is more easily visible.

4.3.4 Leak Detection

4.3.4.1 Leak detection is a regulatory requirement for some chemical processes. If insulating piping and equipment that contains chemicals that fall within the leak detection classification, it is necessary to design the insulation to permit detection of leaks at flanges, valves, and other locations that can be prone to leakage.

4.3.4.2 Leak detection provision can be provided in hot systems by not insulating leak-prone items or by using removable reusable insulation as specified in PIP INSR1000. This approach is not an option for low-temperature systems because there would be no vapor seal and condensation or ice formation can occur. Low-temperature systems require special consideration and should be handled on a case-by-case basis.

4.3.5 Absorption Resistance

The absorption resistance of the insulation material is an important attribute if insulating piping and equipment that contain flammable or explosive chemicals. If leaks occur and the insulation absorbs the chemical, it is possible to build up enough of the flammable or explosive chemical to achieve auto-ignition. It may be necessary to use an appropriate
closed-cell insulation that is compatible with the chemical and does not absorb leaks. It is desirable to provide drainage to enable the leaking chemical to escape from the insulation in a controlled fashion.

4.3.6 Emissivity

4.3.6.1 Emissivity is a measure of a body’s ability to radiate energy. A body that radiates a large amount of energy has an emissivity close to 1, while a material that is a poor radiator has a low emissivity. All materials have a characteristic emissivity. New aluminum jacket has an emissivity of about 0.04, while PVC jacket has an emissivity of about 0.9. The emissivity value can change as the surface characteristics of the insulation change with time.

4.3.6.2 The surface temperature of an insulation system is a function of the emissivity of the jacket material. On a hot insulation system, with all other factors held constant, the outer surface temperature of the insulation jacket is reduced by using a higher emissivity jacket. If personnel protection is an important criteria, it may be possible to reduce insulation thickness by using a high emissivity jacket. On a cold insulation system, the jacket temperature can be raised by using a higher emissivity jacket. If condensation control is an important criteria, the surface temperature can be raised by using a higher emissivity jacket.

5. Corrosion under Insulation

5.1 A full discussion of corrosion under insulation is beyond the scope of this Practice. There are numerous articles available in the technical literature referenced in this Practice. An article in the *ASM Metals Handbook*, Volume 13C, Copyright 2006, page 654 through page 658 covers the subject of corrosion under thermal insulation.

5.2 Stress corrosion cracking (SCC) occurs if a susceptible material is exposed to a specific cracking agent while a tensile stress is present. The stress can be directly applied, such as internal pressure or a piping load, or it can be residual from forming or welding operations. There is disagreement about many aspects of the SCC cause and prevention; however, there is agreement that SCC of 300 series austenitic stainless steel requires water at the metal surface, some level of free chloride ion and a temperature above approximately 140°F (60°C) and below 300°F (150°C ). The source of chloride can be from leachable chloride inherent in the insulation or from atmospheric chloride that enters the insulation system from rain or wash down water. Certain types of insulation are higher in leachable chloride than others. *ASTM C871* describes the standard testing procedure for determining leachable chloride in insulation material. As a general rule, atmospheric chloride is higher close to the seashore than inland, and is higher in industrial areas than in rural areas. The *ASM Metals Handbook*, page 42-60 provides a map showing relative levels of chloride in rainwater in the U.S.

5.3 Mitigation efforts for corrosion under insulation include the following:

a. Proper installation and maintenance of insulation weather jacketing to prevent water ingress
b. Use of low chloride insulation materials
c. Coating the metal to prevent water contact.
**NACE SP 0198-2010** describes control measures for mitigating corrosion under thermal insulation. Common coatings for mitigating corrosion under thermal insulation are epoxy phenolic and coal tar epoxies. **PIP CTSE1000** provides more information on coatings.

### 6. Insulation Material Selection

#### 6.1 General

6.1.1 The appropriate insulation material for a given project is selected on the basis of design criteria that are appropriate for that specific project. Some important design criteria are as follows:

- Operating temperature
- Strength, rigidity, and the ability to resist mechanical abuse and vibration
- Absorption resistance
- Water vapor permeation resistance
- Fire resistance

6.1.2 Not all insulation materials perform equally well with respect to these design criteria. Each insulation type has strengths and weaknesses and the strengths of the material selected for a specific job should be matched to the most important design criteria for that job. For example, a low permeation material should be chosen for a low-temperature application in which permeation resistance is needed to prevent condensation on the surface of the insulated item. A rigid high compressive strength material should be chosen in situations in which mechanical abuse is likely.

#### 6.2 ASTM Considerations

6.2.1 ASTM has identified many of the important material properties that support specific design criteria. There are ASTM test methods for:

- Strength
- Dimensional stability
- Surface burning characteristics
- Water absorption
- Water vapor permeability
- Water wicking
- Water vapor sorption

The ASTM standards that define the requirements for specific insulation materials do so in terms of performance in these various tests.

6.2.2 By comparing the minimum performance requirements defined by ASTM, it is possible to compare different material types to determine which is best for a given application. However, it should be remembered that the ASTM values are minimum requirements and that in some cases, critical values are not included in the ASTM standard for a given material. For example, the standard for mineral fiber, *ASTM C547* does not have a
requirement for water absorption. Instead, mineral fiber is evaluated for water vapor “sorption” using ASTM C1104. ASTM C1104 does not expose the mineral fiber to direct immersion. Instead, it is exposed to water vapor, a less demanding requirement that does not indicate how mineral fiber performs if immersed in water. In other cases, the properties of the insulation change with exposure to elevated temperature. Both perlite and mineral fiber become much more absorbent if exposed to temperatures that are sufficiently high to burn away the binder that is applied when the insulation is made.

6.2.3 There is no ASTM test for water wicking except for aircraft-type glass fiber blanket as published in ASTM C800. Some manufacturers test material using the ASTM C800 procedure however, the appropriateness of this procedure for all materials has not been demonstrated. The relevance of the procedure to real world applications is also not clear. If in doubt about the appropriate use of a specific insulation material contact the owner’s representative for guidance.

6.3 Insulation Materials Properties

Owner should review current ASTM material standards for relevant material properties when selecting materials for a specific application. ASTM C1696 is a good source of min/max physical property values of some insulation materials commonly used for industrial applications.

7. Extent of Insulation

7.1 Extent of insulation refers to what can and cannot be insulated during a project. PIP datasheets INSH1000-D003 and INSC1000-D003 may be used to specify the extent of insulation for a project. The extent of insulation varies depending on the design criteria. For example, in the case of heat conservation, flanges, valves, or other potentially high maintenance items can be left uninsulated to facilitate leak detection and repairs. In the case of cold conservation, piping items cannot be left uninsulated because condensation and ice formation can occur. As a general rule, all low-temperature surfaces should be insulated. Both heat conservation and process stability applications should be insulated as much as possible to ensure these criteria are met.

7.2 If insulating only for mitigating personnel protection, the extent of insulation is quite different than for heat or cold conservation. Personnel protection insulation is only applied to those surfaces with which personnel can make contact under normal operating conditions. If the normal operating temperature is greater than 140°F (60°C), personnel protection insulation is required on all surfaces to 2.13m (7-feet) above grade or platforms, and 0.91m (3-feet) horizontally from the periphery of platforms, walkways, or ladders. In some circumstances, guards or barriers can be substituted for insulation to provide personnel protection if insulation would impair the function of the equipment. A guard is positioned near the pipe or equipment to prevent personnel contact at a specific location. Guards can be fabricated from a variety of materials including sheet or expanded metal. Barriers or signs are used to prevent access to areas where hot equipment is present. An example of a barrier is a chain that bars access to a ladder that leads to a platform where hot equipment is operating. Hot items that typically cannot be insulated are refractory-lined vessels, condensers, or equipment that can be subject to corrosion under insulation.
8. Insulation Thickness

8.1 General

8.1.1 Insulation thickness depends on the design criteria applied to the project. Insulation that is intended to conserve heat is typically installed with a different thickness than insulation designed to protect personnel. There are many variables that influence insulation thickness including:

a. Operating temperature
b. Average ambient weather conditions
c. Insulation material
d. Jacket material
e. Substrate material of construction
f. Basic Design Criteria (paragraph 4.2)

8.1.2 Because each project is unique, the insulation thickness should be calculated specifically for each project. Generic thickness tables are not provided in this Practice because any thickness calculated by 3E Plus is completely dependent upon project specific variables. Instead, information is provided in this Practice on when to use 3E Plus.

8.1.3 Project-specific data sheets, *PIP INEG1000-D002* and *PIP INEG1000-D003*, formatted to record the variables required for 3E Plus calculations, are furnished in the appendix of this Practice. Additional data sheets are furnished to record project specific thicknesses calculated by 3E Plus using project specific parameters.

8.1.4 Blank thickness data sheets are provided to record the calculated thicknesses for both hot and cold services. The datasheets are included in *PIP INSC1000* and *PIP INSH1000*.

8.2 3E Plus

8.2.1 3E Plus can be downloaded free of charge from the NAIMA website at https://insulationinstitute.org/tools-resources/free-3e-plus/. The system of mathematical heat flux equations used in the 3E Plus analysis is based on the equations published in *ASTM C680* and is applicable to most systems typically insulated with bulk-type insulations. 3E Plus can be used to calculate thickness for different design criteria. It can calculate thickness for personnel protection based on easily obtained process data.

8.2.2 3E Plus can also calculate an economic thickness that is optimized based on a series of economic variables that should be provided by the designer. To obtain an accurate economic thickness, these variables should be determined for each project. Using the defaults supplied in the program does not produce an accurate result. The 3E Plus user’s guide provides a detailed description of the basis for the economic analysis that goes beyond the scope of this discussion. Among the data required by 3E Plus is climate information that requires both ambient temperature and wind speed. Both affect heat transfer. Climate data for many locations in the U.S. is available at www.noaa.gov, the website of the National Oceanic and Atmospheric Administration (NOAA). The actual climatic data used depends upon the design criteria of the project and the location of the item to be insulated.
8.2.3 Insulation used for condensation control should be designed for the expected humidity conditions. 3E Plus can be used for the design of low-temperature systems. If a low process temperature is specified, 3E Plus should be supplied with the ambient temperature and relative humidity. The highest expected relative humidity at the highest expected ambient temperature can provide the worst-case dew point temperature. The insulation thickness should be selected so that the surface temperature of the insulation jacket is greater than the calculated dew point temperature. The surface temperature of the insulation system can be significantly altered by changing the emissivity of the jacket. Using a jacket material with an emissivity close to 1 raises the temperature of the jacket surface and reduces the thickness of insulation required. 3E Plus can be used to calculate the effect of emissivity on surface temperature. If making condensation control calculations, it is important to include an accurate wind speed because the required thickness for condensation control goes up as wind speed drops. An under estimate of wind speed can result in excessive thickness and an over estimate can result in unwanted condensation on the jacket surface.

8.2.4 Process stability requirements are also project specific. 3E Plus can calculate heat loss or heat gain for user-specified operating conditions. The allowable amount of heat loss or gain depends upon the process and should be determined for the specific project in consultation with the process designer.

9. Type Codes

9.1 General

9.1.1 Insulation type codes should be used on P&IDs, data sheets, piping isometrics, and other project documents.

9.1.2 Insulation type codes consist of up to four characters. The first two characters are defined in this Practice. The second two characters can be used to define additional requirements such as combination systems or special requirements.

9.2 Hot Insulation Types

9.2.1 HC - Heat Conservation Insulation

9.2.1.1 Heat conservation insulation should be designated with the code HC.

9.2.1.2 The primary consideration for using heat conservation insulation should be economics.

9.2.1.3 Design of heat conservation insulation should be based on local average ambient climatic conditions and project economies.

9.2.1.4 Heat conservation insulation should be used if normal operating temperature is greater than 140°F (60°C), unless loss of heat is desirable.

9.2.2 PS – Process Stability Insulation

9.2.2.1 Process stability insulation should be designated with the code PS.

9.2.2.2 The primary consideration for using process stability insulation should be control of process temperatures, including impact because of sudden changes in ambient conditions.
9.2.2.3 Design of process stability insulation should be based on anticipated extremes in ambient conditions.

9.2.3 **PP – Personnel Protection Insulation**

9.2.3.1 Personnel protection insulation should be designated with the code PP.

9.2.3.2 The primary consideration for using personnel protection insulation should be to limit the temperature of exposed surfaces.

9.2.3.3 Design of personnel protection insulation should be based on summer dry bulb temperature and low wind velocity to reflect a worst-case condition.

9.2.3.4 Personnel protection insulation should be used if normal temperature of a surface is greater than 140°F (60°C) and if the surface is in an area that is accessible to personnel. Accessible area is defined as an area in which personnel regularly perform duties other than maintenance during plant operation.

9.2.3.5 Personnel protection should be provided to 7 feet (2.13 m) above grade or platforms and 3 feet (0.91 m) horizontally from the periphery of platforms, walkways, or ladders.

9.2.3.6 Personnel protection should consist of insulation, shields, guards, or barriers.

9.2.3.7 If corrosion under the insulation is a concern, or if heat loss is desirable, use of fabricated shields/guards in lieu of insulation should be considered.

9.2.4 **PF – Prevention from Freezing Insulation**

9.2.4.1 Freeze prevention insulation should be designated with the code PF.

9.2.4.2 The primary consideration for the use of this category is protection from freezing.

9.2.4.3 Design of prevention from freezing insulation should be based on local climatic conditions.

9.2.4.4 Prevention from freezing insulation can be combined with other types of insulation.

9.3 **Cold Insulation Types**

9.3.1 **CC – Cold Service Insulation**

9.3.1.1 Cold service insulation should be designated with the code CC.

9.3.1.2 The primary consideration for using cold service insulation should be based on maximum allowable heat gain.

9.3.1.3 The design of cold service insulation should be based on control of heat gain and limiting surface condensation if the operating temperature is below ambient.

9.3.1.4 Cold service insulation should be sealed against atmospheric moisture intrusion and subsequent wetting/icing of the insulation. Sealing typically involves special consideration for design of equipment and insulation support details.

9.3.2 **CP – Condensation Control Insulation**

9.3.2.1 Condensation control insulation should be designated with the code CP.

9.3.2.2 The only consideration for use of condensation control insulation should be control of external surface condensation.
9.3.2.3 Design of condensation control insulation should be based on the normal operating temperature and local climatic conditions. In some humid climates, it is impractical to prevent condensation 100 percent of the time.

9.3.2.4 Use of surface finishes to control surface emissivity can be considered to reduce insulation thickness.

9.3.3 DT – Dual Temperature Insulation

9.3.3.1 Dual temperature insulation should be designated with the code DT.

9.3.3.2 Dual temperature insulation is typically used for services operating below ambient, but subject to cyclic or regeneration operation above 121°C (250°F).

9.3.3.3 The design of dual temperature insulation should be based on limiting surface condensation for operation below ambient and limit heat loss during cycling or regeneration.

9.4 Insulation Types for Traced and Energy Transfer Jacketed Systems

9.4.1 General Considerations

9.4.1.1 The primary consideration for using tracing or heat transfer jacketing and associated insulation should be control of process temperatures.

9.4.1.2 Design of insulation should be based on the operating temperature, heat transfer jacketing temperature, or the tracer temperature. The same insulation thickness as that for heat conservation (HC) or cold service (CC), as appropriate, should be used unless design optimization dictates a different thickness.

9.4.1.3 Optimization of the tracer or heat transfer jacketing design and insulation thickness should be required if specified.

9.4.1.4 Oversize insulation should be considered to accommodate tracer(s) or heat transfer jacketing.

9.4.1.5 Unless otherwise specified by the purchaser, grooving of insulation to accommodate tracing is not recommended.

9.4.2 ET – Electric Traced

Electric tracing and associated insulation should be designated with the code ET.

9.4.3 ST – Steam Traced

Steam tracing and associated insulation should be designated with the code ST.

9.4.4 SJ – Steam Jacketed

Steam jacketing and associated insulation should be designated with the code SJ.

9.4.5 HT – Hot Fluid Traced

Hot fluid tracing (except steam) and associated insulation should be designated with the code HT.

9.4.6 HJ – Hot Fluid Jacketed

Hot fluid jacketing and associated insulation should be designated with the code HJ.
9.4.7 CT – Chilled Fluid Traced
Chilled fluid tracing and associated insulation should be designated with the code CT.

9.4.8 CJ – Chilled Fluid Jacketed
Chilled fluid jacketing and associated insulation should be designated with the code CJ.

9.5 AC – Acoustic Control Insulation
9.5.1 Acoustic control insulation should be designated with the code AC.

9.6 FP – Fire-Protection Insulation
9.6.1 Fire-protection insulation should be designated with the code FP.
## HOT SERVICE INSULATION DESIGN PARAMETERS

<table>
<thead>
<tr>
<th>PIP DOC NUMBER / PROJ DOC NUMBER</th>
<th>TITLE</th>
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## COLD SERVICE INSULATION DESIGN PARAMETERS

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HEAT CONSERVATION DESIGN BASIS:

- Ambient temperature (average annual) °C °F
- Wind speed (average annual) m/s mph
- Insulation finish emissivity
- Minimum insulation thickness mm in.

PERSONNEL PROTECTION DESIGN BASIS:

- Ambient temperature (average summer maximum) °C °F
- Maximum surface temperature °C °F
- Wind speed m/s mph
- Insulation finish emissivity
- Minimum insulation thickness mm in.

ECONOMIC THICKNESS CALCULATION BASIS:

- Interest rate %
- Effective income tax %
- Annual insulation maintenance %
- Annual physical plant maintenance %
- Annual fuel inflation rate %
- Physical plant annual operating hours hr/year
- Physical plant depreciation period years
- New insulation depreciation period years
- First year cost of energy (Natural Gas) $/M³ $/Mft³
- Heating value J/m³ Btu/ft³
- First year cost of energy (______________) $/M³
- Heating value (______________)
- Design factor for thermal conductivity
- Design factor for piping complexity simple complex
- Productivity factor
- Insulation installation labor rate $/hr

Insulation material cost:

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<td>NPS 2 x 2 in.</td>
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NOTES:
### Heat Gain Limit Design Basis:

- Maximum heat gain - insulation surface: [ ] W/m², [ ] Btu/hr·ft²
- Design ambient temperature: [ ] °C, [ ] °F
- Wind speed (average annual): [ ] m/s, [ ] mph
- Insulation finish emissivity
- Design factor for thermal conductivity
- Minimum insulation thickness: [ ] mm, [ ] in.

### Condensation Control Design Basis:

- Design ambient temperature: [ ] °C, [ ] °F
- Design relative humidity: [ ] %
- Design dew point temperature: [ ] °C, [ ] °F
- Wind speed: [ ] m/s, [ ] mph
- Insulation finish emissivity
- Design factor for thermal conductivity
- Minimum insulation thickness: [ ] mm, [ ] in.

### Notes:

- [ ]