

Corrosion Under Insulation and Fireproofing

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Corrosion Under Insulation and Fireproofing

1 Scope

This recommended practice covers the design, maintenance, inspection, and mitigation practices to address external corrosion under insulation (CUI) and corrosion under fireproofing (CUF). The document discusses the external corrosion of carbon and low alloy steels under insulation and fireproofing and the external chloride stress corrosion cracking (ECSCC) of austenitic and duplex stainless steels under insulation. The document does not cover atmospheric corrosion or corrosion at uninsulated pipe supports but does discuss corrosion at insulated pipe supports.

The purpose of this recommended practice is to:

- help owner/users understand the complexity of the many CUI/CUF issues;
- provide owner/users with understanding on the advantages and limitations of the various nondestructive examination methods used to identify CUI and CUF damage;
- provide owner/users with an approach to risk assessment (i.e. likelihood of failure and consequence of failure) for CUI and CUF damage; and
- provide owner/users guidance on how to design, install, and maintain insulation systems to avoid CUI and CUF damage.

The practices described in this document apply to pressure vessels, piping, and storage tanks and spheres. The document discusses the factors impacting the damage mechanisms, the guidelines to prevent external corrosion/cracking under insulation, the maintenance practices to avoid damage, the inspection practices to detect/assess damage, and the guidelines for risk assessment of equipment or structural steel subject to CUI and CUF damage.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements and/or recommendations of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API 510, *Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair, and Alteration*

API 570, *Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems*

API Recommended Practice 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*

API Recommended Practice 580, *Risk-Based Inspection*

API Recommended Practice 581, *Risk-Based Inspection Methodology*

API Standard 653, *Tank Inspection, Repair, Alteration, and Reconstruction*, Fifth Edition

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1

ablative coating

A coating that is designed to dissipate heat by oxidative erosion of a heat protection layer (i.e. charring) while protecting the underlying metal substrate.

3.1.2

aerogel

A homogeneous, low-density solid-state material derived from a gel, in which the liquid component of the gel has been replaced with a gas. The resulting material has a porous structure with an average pore the mean free path of air molecules at standard atmospheric pressure and temperature.

3.1.3

americium 241

Nuclear isotope that emits fast, high-energy neutron radiation; used to detect slow, thermal neutrons generated by collision with hydrogen atoms.

3.1.4

amphoteric

Capable of reacting chemically either as an acid or as a base.

3.1.5

calcium silicate

Insulation that is composed principally of hydrous calcium silicate and usually contains reinforcing fibers.

3.1.6

cellular glass

Insulation that is composed of glass processed to form a rigid foam having a predominately closed-cell structure.

3.1.7

cementitious coating

A coating that contains Portland cement as one of its components and is held onto the applied substrate by a binder; also defined as “binders, aggregates and fibers mixed with water” in API 2218.

3.1.8

chlorosulfonated polyethelene

CSPE

A polymer used for nonmetallic weather jacketing.

3.1.9

cladding

See “jacketing.”

3.1.10

cobalt 60

Nuclear isotope that emits gamma radiation with far greater penetrating power than iridium 192; used to expose radiographic film, computed radiography (CR) plates, linear diode array (LDA) and digital detector array (DDA) detectors.

3.1.11**cold piping**

Piping systems normally operating below the dew point.

3.1.12**comparator block**

A steel object such as a steel ball or block used to calculate the geometric unsharpness factor for distortion on a radiograph of a wall pipe. The geometric unsharpness factor is then used to calculate the true thickness of the pipe wall.

3.1.13**composite wrap**

A wrapping system composed of multiple nonmetallic fiber/polymer layers to repair corroded piping.

3.1.14**corrosion under fireproofing****CUF**

Corrosion of piping, pressure vessels, and structural components resulting from water trapped under fireproofing.

3.1.15**corrosion under insulation****CUI**

External corrosion of materials of construction piping, pressure vessels, and structural components resulting from water trapped under insulation; ECSCC of austenitic and duplex stainless steel under insulation is also classified as CUI damage.

3.1.16**dead-leg**

Section of piping or a piping system where there is no significant flow; examples include: blanked branches, lines with normally closed block valves, lines that have one end blanked, pressurized dummy support legs, stagnant control valve bypass piping, spare pump piping, level bridles, relief valve inlet and outlet header piping, pump trim bypass lines, high point vents, sample points, drains, bleeders, and instrument connections.

3.1.17**deluge system**

Defined in NFPA 15, an installation equipped with multiple open nozzles connected to a water supply by means of a deluge valve, which allows water to flow from all nozzles simultaneously. This is similar to a water spray system, but does not use directional water spray nozzles to achieve a specific water discharge and distribution. In the refining industry, the term "deluge system" is generally a system without nozzles in which all the water is applied from an open pipe. API 2510 and API 2510A describe such a system at the top of a vessel that allows water to run down the sides in a thin film, frequently using a weir to improve distribution and assist the even flow of water over the protected vessel.

3.1.18**dense concrete fireproofing**

Concretes made with Portland cement that can be formed in place or pneumatically sprayed to the required thickness using steel reinforcement.

3.1.19**expanded perlite**

A natural volcanic glass similar to obsidian that has been finely ground and subjected to extreme heat, causing the particles to become considerably expanded and porous because of release of water.

3.1.20**external chloride stress corrosion cracking****ECSCC**

Surface initiated cracking in austenitic and duplex stainless steels and some nickel base alloys under the combined action of tensile stress, temperature, and an aqueous chloride environment.

3.1.21**fiberglass (glass wool)**

A synthetic vitreous fiber insulation made by melting predominantly silica sand and other inorganic materials, and then physically forming the melt into fibers.

3.1.22**fireproofing**

A systematic process, including design, material selection, and the application of materials, that provide a degree of fire resistance for protected substrates and assemblies.

3.1.23**fluoroscopy**

Real-time X-ray system based on the principal of fluorescing screens.

3.1.24**gadolinium 153**

Nuclear isotope that emits gamma radiation.

3.1.25**gamma radiation**

Photons or packets of energy emitted from certain nuclear isotopes such as iridium 192 or cobalt 60.

3.1.26**hydrophobic**

Having little affinity for water, nonwetable.

3.1.27**ice lens**

A localized zone of ice accumulation.

3.1.28**ice-to-air interface**

Transition points on cold service insulation systems operating below the freezing point that forms an ice-to-air interface; depending on time of year (such as summer and winter months), the size of the ice at these locations change by continually freezing and thawing.

3.1.29**insulating/insulative coating**

Composite insulators with a thickness of 20–200 mils and operating temperature ranges 40–500 °F used for personnel protection, energy and thermal conservation, and preventing corrosion under insulation.

3.1.30**intumescent coating**

A fire retardant coating that, when heated, produces nonflammable gases that are trapped by the film, converting them to a foam and thereby insulating the substrate.

3.1.31**iridium 192**

Nuclear isotope that emits gamma radiation; used to expose radiographic film computed radiography (CR) plates, linear diode array (LDA) and digital detector array (DDA) detectors.

3.1.32**jacketing**

The protective covering that is applied over insulation; also referred to as “sheathing” or “cladding.”

3.1.33**lagging**

Another name for insulation.

3.1.34**lightweight cementitious fireproofing**

A sprayed or troweled coating formulated from Portland cement and lightweight aggregate, such as vermiculite, perlite, and diatomite in place of the usual sand and stone.

3.1.35**lightweight concrete fireproofing**

A concrete that uses very light aggregate, such as vermiculite or perlite (instead of gravel), with cements that are resistant to high temperatures.

3.1.36**linear diode array****LDA**

A linear diode array is used for digitizing radiographic images. The LDA system consists of an array of photodiode modules. The diodes are laminated with a scintillation screen to create X-ray sensitive diodes.

3.1.37**mastic**

A pasty material used as a protective coating or cement.

3.1.38**microporous flexible thin blanket insulation**

Material in the form of compacted powder with an average interconnecting pore size comparable to or below the mean free path of air molecules at standard atmospheric temperature and pressure. Microporous insulation may contain fibers to add integral strength and may contain opacifiers to reduce the amount of radiant heat transmitted.

3.1.39**mineral fiber**

Synthetic vitreous fibers manufactured from rock, slag, or glass.

3.1.40**mineral wool**

A synthetic vitreous fiber insulation made by melting predominantly igneous rock, and/or furnace slag, and other inorganic materials and then physically forming the melt into fibers. To form an insulation product, there are often other materials applied to the mineral wool such as binders, oils, etc.

3.1.41**neutron backscatter testing**

A test method that uses high-energy (fast) neutrons to detect the presence of hydrogen atoms.

3.1.42**perlite**

Natural volcanic material that is heat expanded to a form used for lightweight concrete aggregate and fireproofing.

3.1.43**photolysis**

Chemical decomposition of polystyrene foam caused by light or other electromagnetic radiation.

3.1.44**polyisocyanurate foam**

A closed-cell, thermoset, plastic foam formed by combining isocyanurate, polyol, surfactants, catalysts, and blowing agents.

3.1.45**PT**

Liquid penetrant examination method.

3.1.46**pulsed eddy current examination method****PEC**

An eddy current examination method that uses a stepped or pulsed input signal instead of a continuous signal used by conventional eddy current techniques. This technique has a greater penetration depth and is less sensitive to lift-off than conventional eddy current techniques.

3.1.47**real-time radiographic examination method****RTR**

A nondestructive test method whereby an image is produced electronically rather than on film so that very little lag time occurs between the item being exposed to radiation and the resulting image.

3.1.48**reliability-centered maintenance**

A process used to determine the maintenance requirements of any physical asset in its operating context.

3.1.49**sheathing**

See "jacketing."

3.1.50**silica aerogel flexible blanket**

A flexible insulation containing a composite of aerogel, fibrous carrying media, or reinforcements, or a combination thereof.

3.1.51**structural steel**

Steel shaped for use in construction including I-beams, vessel skirts, and saddles for exchangers and other horizontal vessels.

3.1.52**subliming compound**

A coating where the active ingredient absorbs heat as it changes directly from a solid to a gas phase; as in the case of ablative coatings, intumescent are incorporated to provide an additional insulating layer.

3.1.53**transition points**

Protrusions through the insulation system (e.g. vents, drains, supports, nozzles, instrument connections, etc.) on carbon steel piping and equipment operating at below ambient or cold service temperatures (includes those operating below 10 °F).

3.1.54**vermiculite**

A group of minerals characterized by their ability to expand into long, wormlike strands when heated; this expansion process is called “exfoliation.”

3.1.55**water resistant**

Resistant but not impervious to penetration by water.

3.1.56**X-ray**

Photons or packets of energy emitted from the cathode ray tube of an X-ray unit when the cathode is bombarded with electrons.

3.2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

AWT	average wall thickness
CR	computed radiography
CSPE	chlorosulfonated polyethylene
CUF	corrosion under fireproofing
CUI	corrosion under insulation
DDA	digital detector array
ECSCC	external chloride stress corrosion cracking
EPS	expanded polystyrene
ET	eddy current examination method
FFS	fitness-for-service
GRP	glass-reinforced plastic
GWT	guided wave testing
ID	inside diameter
IR	infrared imaging
MDI	moisture detection imaging
MOC	management of change
NPS	nominal pipe size
OD	outside diameter

PEC	pulsed eddy current examination method
PT	liquid penetrant examination method
PSP	photostimulable phosphor
PVC	polyvinyl chloride
RBI	risk-based inspection
RTR	real-time radiographic examination method
SCC	stress corrosion cracking
TSA	thermal spray aluminum
UV	ultraviolet
XPS	extruded polystyrene

4 Introduction to the Causes of Damage

4.1 General

Thermal insulation is used on the exterior of equipment and piping for a variety of reasons including:

- heat conservation [usually >200 °F (93 °C)];
- cold conservation (refrigeration systems) [usually <40 °F (4 °C)];
- personnel protection [usually >140 °F (60 °C)];
- freeze protection/heat tracing;
- condensation control;
- acoustic (noise) reduction;
- fire protection;
- process control.

By contrast, fireproofing is used on structural steel solely to minimize, for a period of time, the impact of temperatures generated during a fire on structural supports for pressure vessels (i.e. skirts) or piping (I-beams). Despite their different applications, CUI and CUF are similar degradation mechanisms in that corrosion of the steel substrate may occur in certain situations when water accumulates at the underlying steel surface. In stainless steels, CUI damage takes the form of environmental cracking.

In addition to this document, a discussion of the causes of CUI and CUF damage, inspection methods for detecting damage, and other CUI- and CUF-related topics can be found in API 571, ASTM STP 880, and IMMM EFC 55.

4.2 CUI in Carbon and Low Alloy Steels

4.2.1 General

CUI is defined as the external corrosion or cracking of piping and vessels that occurs when water gets trapped beneath insulation. CUI damage takes the form of localized external corrosion in carbon and low alloy steels. The factors that affect the amount of CUI damage under insulation include:

- duration of the exposure to moisture;
- cyclical operation in and out of CUI range and/or intermittent operation;
- frequency of the exposure to moisture;
- corrosivity of the aqueous environment;
- condition of protective barriers (e.g. coating and jacketing);
- equipment design issues;
- service temperature—cold can sweat/stay wet, hot may drive off moisture;
- insulation type;
- condition of weather barriers and caulking;
- type of climate;
- site maintenance practices;
- leaking steam-tracing systems;
- proximity to humidity-causing equipment, such as cooling towers;
- proximity to saltwater; and
- high industrial area acidic rain water.

CUI damage is characterized by either general metal wastage or pitting due to the localized breakdown of passivity. It is a form of oxygen corrosion and occurs on carbon and low alloy steel when exposed to moisture and oxygen. Damage occurs when water is absorbed by or collected beneath the insulation due to breaks in the insulation or jacketing (cladding) and remains unable to evaporate from the insulation; therefore, the moisture contacts and stays on the underlying exposed steel. Theoretically, this occurs at metal temperatures between 32 °F (0 °C) and 212 °F (100 °C). Water may come from numerous sources such as rainwater, a deluge system, spillage from process operations, leaking steam tracing, or condensation on the metal surface in humid environments. Exposure to water can and will damage nonemersion grade paint. Also, holidays in the paint allow for contact with electrolytic and can undermine the paint. While painting is a best practice, the metal will still be prone to CUI when insulated.

When determining CUI susceptibility, a much broader operating temperature range should be considered, typically from 10 °F to 350 °F (−12 °C to 177 °C) because of fluctuations in operating temperature, ineffective insulation maintenance, type of insulation, insulation or coating system damage, temperature gradients within the equipment considered (long pipe runs, fractionation columns, heat exchangers, etc.), and various operating modes. Contaminants in the insulation, such as chlorides and sulfides, may contribute to the corrosivity of the environment.

In some instances, these differences arise because users have reported actual metal temperature for CUI incidents, other users have reported actual process temperature in reports of CUI damage, and some have introduced a margin of safety. This has led to an expanding of the range where CUI damage may occur. The temperature range that CUI damage is most severe depends on many different factors but in many areas has been found to be at metal temperatures between 170 °F and 230 °F (77 °C and 110 °C) where corrosion reaction kinetics are the highest.

All operating conditions should be considered, including the out-of-service state, for equipment that is offline at ambient temperatures for significant periods of time. Equipment that cycles in and out of the CUI range during regeneration cycles, or is frequently out-of-service at ambient conditions, can experience aggressive CUI damage even though when in normal operation it is outside the CUI temperature range.

4.2.2 CUI Damage Below 32 °F (0 °C) and Above 212 °F (100 °C)

The temperature range quoted for CUI can vary from one document to another and may list temperatures where liquid water would not be predicted [i.e. below 32 °F (0 °C) and above 212 °F (100 °C)]. This is because users sometimes report the temperature where damage occurred based on the process operating temperature rather than the actual metal surface temperature. The key factor for CUI damage to occur is that a corrosive aqueous layer be present on the insulated metal surface during any operating period or during downtime.

One possible situation is where water breaches the insulation coming in contact with the metal surface temperature between 212 °F and 350 °F (100 °C and 177 °C). CUI damage could be occurring as the result of continual flashing of water at the hot metal surface that can concentrate chlorides on the metal surface. Even at surface metal temperatures up to 600 °F (316 °C), CUI could occur during operation if water reaches the metal surface during a shutdown period and flashes off during start-up. Another instance where CUI can occur is where deposits in a dead-leg reduce the surface metal temperature sufficiently to allow CUI to take place. Other examples include nozzles, platform support protrusions, etc. CUI damage may also occur in equipment operating at process temperatures below 32 °F (0 °C) as the result of cyclic exposure conditions above 32 °F (0 °C) or frequent unit shutdown. It is more important to determine whether water is breaching the insulation system rather than dwelling on what the exact temperature of the insulated metal surface during normal operation. It should be noted that it is very difficult for insulation jacketing/cladding systems to be leak tight. Section 7 and API 571 provide information on CUI inspection practices.

4.3 CUI in Austenitic and Duplex Stainless Steels

CUI damage in austenitic and duplex stainless steels is a form of ECSCC. As with all forms of stress corrosion cracking (SCC), cracking occurs when a susceptible metallurgy is exposed to the combined action of a corrosive environment and an applied/residual tensile stress. Susceptible materials include Type 300 series austenitic stainless steels. Duplex stainless steels, although more resistant than austenitic stainless steels, are not immune. A corrosive environment occurs when chlorides concentrate under the insulation at the surface of the austenitic stainless or duplex steel when the insulation becomes wet. Residual cold work from fabrication or residual welding stresses provides the tensile stresses necessary promote cracking.

Most CUI damage in austenitic stainless steels occurs at metal temperatures between 140 °F and 350 °F (60 °C and 177 °C), although exceptions have been reported at lower temperatures. Below 120 °F (49 °C), it is difficult to concentrate significant amounts of chlorides, whereas above 350 °F (177 °C), water is not normally present and CUI damage is infrequent. It should be noted that even austenitic stainless steel piping that normally operates above 500 °F (260 °C) can suffer severe ECSCC during start-up after insulation gets soaked from deluge system testing, from fire water, or from rain during downtime or the leachable chlorides from insulation. Typically, CUI damage in austenitic and duplex stainless steels goes unnoticed until insulation is removed or a leak occurs.

CUI damage in duplex stainless steels occurs at higher temperatures than observed for austenitic stainless steels. Figure 1 shows the results of SCC tests conducted on austenitic and duplex stainless steels. As can be seen from these results, SCC of duplex stainless steels does not occur until about 285 °F (140 °C) at very high chloride concentration levels. In general, there have been few reported cases of cracking in the industry, but those that have been reported were under severe conditions where SCC could be predicted. Some of the failures reported have been on offshore facilities and were attributed to ECSCC on relatively hot equipment. API 938-C discusses the use of duplex stainless steels in the refining industry.

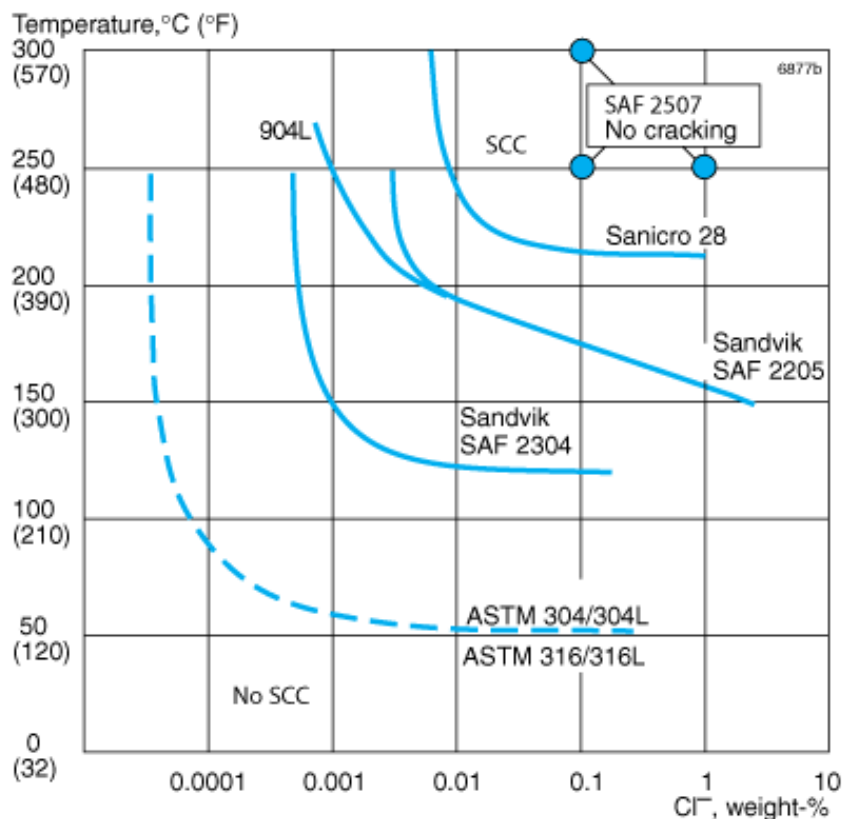


Figure 1—SCC Tendency of Austenitic and Duplex Alloys ¹

4.4 CUF in Carbon and Low Alloy Steels

Fireproofing is used on structural steel, supporting piping, and pressure vessels in process units (i.e. I-beams and skirts) to minimize the escalation of a fire that would occur with the failure of structural steel supporting piping and pressure vessels. Fireproofing is designed to extend the time it takes for structural steel from reaching 1000 °F (540 °C) and allow more time for site personnel to control the fire. At 1000 °F (540 °C), the tensile strength of carbon steel is reduced to roughly 50 % of its room temperature value and impacts the load-bearing ability of these components. The premature failure of these structural supports could add significant fuel to the fire as the equipment or piping collapse can result in loss of containment of other flammable fluids.

¹ <https://www.materials.sandvik/en/materials-center/material-datasheets/tube-and-pipe-seamless/sandvik-saf-2507>.

Localized CUF damage tends to occur in highly industrialized areas with high SO_2 levels in the atmosphere or marine environments when operating, either continuously or intermittently, in the temperature range of 25 °F to 250 °F (−4 °C to 121 °C). When high-chloride-containing water is used to mix concrete fireproofing, metal loss can be quite severe. Some older installations involved solvent reduction (i.e. thinning) of the coating material with chlorinated solvents when the coating was applied during hot, dry weather. Some of the chlorinated solvent can remain in the dried film and produce hydrochloric acid with aging. In addition, prolonged exposure to heat at less than the design temperature may allow for the slow release of acid and subsequent corrosion. This is because the intumescent response to heat is acid activated and may not act instantaneously at the design temperature in response to a fire, typically 392 °F to 482 °F (200 °C to 250 °C).

The corrosion products resulting from CUF can promote cracking or spalling of the fireproofing. This occurs because the corrosion products formed [i.e. essentially iron oxides (Fe_2O_3 and Fe_3O_4)] have a density that is roughly 33 % lower than carbon steel. As a result, the corroded metal occupies a greater volume than the original uncorroded steel, exerting tensile stresses on the fireproofing. Cracking of the fireproofing occurs when sufficient corrosion product builds up between the fireproofing and the underlying steel. Cracking and staining of the fireproofing provide visual evidence that corrosion is occurring on the underlying steel.

4.5 CUI on Aluminum Piping

Aluminum piping is commonly used in processes that perform liquefaction of various gases. Because of the nature of the process, extremely cold temperatures occur during operation. Condensation is common on the surface of piping with the differential surface temperature as compared to ambient.

In most cases, the aluminum piping exposed to cold temperature is insulated. At points of breach in the insulation, moisture in the atmosphere condenses on cold pipe surfaces. Moisture on aluminum pipe in the presence of differential materials such as carbon steel, stainless steel, or copper can initiate galvanic corrosion. Additionally, in marine environments, chlorides can initiate pitting and cracking of aluminum alloys.

Insulation of complex piping geometry results in large areas of piping encapsulated within insulation boxes. Visual inspection is not possible until insulation boxes are emptied. Wet areas within these encapsulation boxes create a high probability of degradation due to corrosion.

Piping support equipment can cause accelerated corrosion points. An example of this accelerated corrosion is stainless steel “U” bolts used to secure piping to structures or support ancillary items such as insulation.

Ice forming on the pipe surface also creates a wet area and hinders visual inspection. Cyclic service creates additional wet conditions during ice thaw.

Saltwater ingress associated with residual stress and crevice corrosion can cause failure of aluminum piping by SCC.

5 Areas Susceptible to Damage

5.1 General

Under the right temperature conditions, CUI or CUF damage can occur at any location that is insulated or fireproofed. CUI and CUF are somewhat insidious in that regard. It is not uncommon to find CUI/CUF damage in locations remote from the more predictable and susceptible locations. However, there are some areas within facilities that experience has shown have a higher susceptibility for damage. In general, areas with severe CUF damage are easier to identify visually than CUI damage because of cracks and staining of the fireproofing. Certain areas and types of equipment have a higher susceptibility for CUI damage.

5.2 General Areas of Damage

There are a number of locations in oil or chemical processing facilities where CUI damage or CUF has a higher likelihood. Areas common to all equipment types are listed in Table 1.

Table 1—Locations for CUI Throughout Process Facilities

Equipment Type	Potential Locations
General areas	Areas downwind of cooling towers exposed to cooling tower mist
	Areas of protrusions (i.e. transition points) through the jacketing at manways, nozzles, vessel/piping supports, and other components
	Areas of protrusions through insulation for equipment/piping operating at or below ambient, or in cold service
	Areas with insulation plugs, especially where they have been improperly installed, damaged, or misplaced
	Areas where insulation jacketing is damaged or missing
	Areas where caulking is missing or hardened on insulation jacketing
	Areas where the jacketing system is bulged or stained
	Areas where banding on jacketing is missing
	Areas where thickness monitoring plugs are missing
	Areas where vibration has caused damage to the insulation jacketing
	Areas exposed to steam vents
	Areas exposed to process spills, the ingress of moisture, or acid vapors
	Areas exposed to deluge systems
	Areas insulated solely for personnel protection
	Areas under the insulation with deteriorated coatings or wraps
	Areas with leaking steam tracing
	Pipe and flanges on pressure safety valves
	Systems that operate intermittently above 250 °F (121 °C)
	Systems operating below the atmospheric dew point
	Systems that cycle through the atmospheric dew point
	Ice-to-air interfaces on insulated systems that continually freeze and thaw
	Dead-legs

Table 2—Locations for CUI/CUF on Vessels

Equipment Type	Potential Locations
Pressure vessels	Insulation support rings below damaged or inadequately caulked insulation on vertical heads and bottom zones
	Stiffening rings on insulated vessels/columns in vacuum service
	Insulated zone at skirt weld
	Insulated leg supports on small vessels
	Ladder and platform attachments
	Termination of insulation at nozzles and saddles
	Fireproofed skirts (CUF)
	Anchor bolts (CUF)
	Bottom of horizontal vessels (i.e. lower third to half of vessel)
	Irregular shapes that result in complex insulation installations (e.g. davit arm supports, lifting lugs, body flanges, etc.)

All equipment is shut down at some time or other. The length of time and the frequency of the downtime spent at ambient temperature may well contribute to the amount of CUI that occurs in the equipment. An example of damage to the jacketing that would allow water to saturate the insulation is similar to what is shown in Figure 2.

5.3 Pressure Vessels

In addition to the areas listed in Table 1, there are other areas in vessels, columns, drums, and heat exchangers where CUI may have a higher likelihood. These are shown in Table 2.

5.4 Piping

5.4.1 General

In addition to the areas listed in Table 1, there are other areas in piping where CUI may have a higher likelihood, and this includes process piping, refrigerated piping, piping at or below grade, pipe supports, or where there is a moisture leak spot. Figure 3 shows a CUI failure of piping in a compressor recycle line. Experience has shown that people will consider cold piping that operates outside of the given materials CUI range to be not susceptible to CUI and later find that nozzles, supports, insulation terminations are warmer, offering a transition into the CUI range.

Susceptible locations for CUI and CUF in piping are listed in Table 3.

Table 3—Susceptible Locations for CUI and CUF in Piping

Equipment Type	Potential Locations
Piping	Dead-legs, vents, and drains
	Pipe hangers and supports
	Valves and fittings
	Bolted on pipe shoes
	Insulation plugs, especially where they have been improperly installed, damaged, or misplaced
	Steam-tracing/electric-tracing tubing penetrations
	Termination of insulation at flanges and other piping components
	Areas where smaller branch connections intersect larger diameter lines
	Low points in piping, such as bottom of vertical runs
	Close proximity to water (e.g. wharf) and/or ground (e.g. increased absorption)
	Wet due to flooding or submerging into water
	Damage due to foot traffic

5.4.2 Cold Piping

In this document, cold piping is considered to be piping carrying liquid or gases that cool the piping to temperatures below the dew point. Cold piping is prone to corrosion because of condensation with CUI often occurring in locations remote from the predictable and susceptible locations. The condensation present can freeze in cases where the temperature of the outside surface of the piping decreases below freezing. In many cases, such as ammonia terminals, piping temperatures can swing from ambient to -30°F (-34°C) during periods when ammonia is flowing in the piping. This temperature swing leads to continuous freezing and thawing, and results in wet conditions that increase the piping system susceptibility to CUI damage. Additionally, other equipment and components such as tanks, pressure vessels, pipe supports, and flanges connected by this piping may be affected by the runoff of melting ice or condensed water.

Ice layers can form on piping operating at temperatures below freezing and can obscure the view of external surface damage due to a continuous wet environment. In many cases, piping used for these cold temperature applications is insulated. Frequent chilling and condensation accelerates corrosion at points where the insulation system is breached, which exposes the surface of the piping to the atmosphere (i.e. ice-to-air interfaces). Water ingress, due to poorly sealed insulation jacketing, can result in ice buildup causing swelling of the insulation and create a larger area of damage to the insulation system. This repeated condition creates more and more exposure and susceptibility to corrosion.



Figure 2—Jacketed Piping with Missing Insulation Plug (top photo) Allowing Water Ingress and Subsequently Corrosion on Piping Elbow (bottom photo)

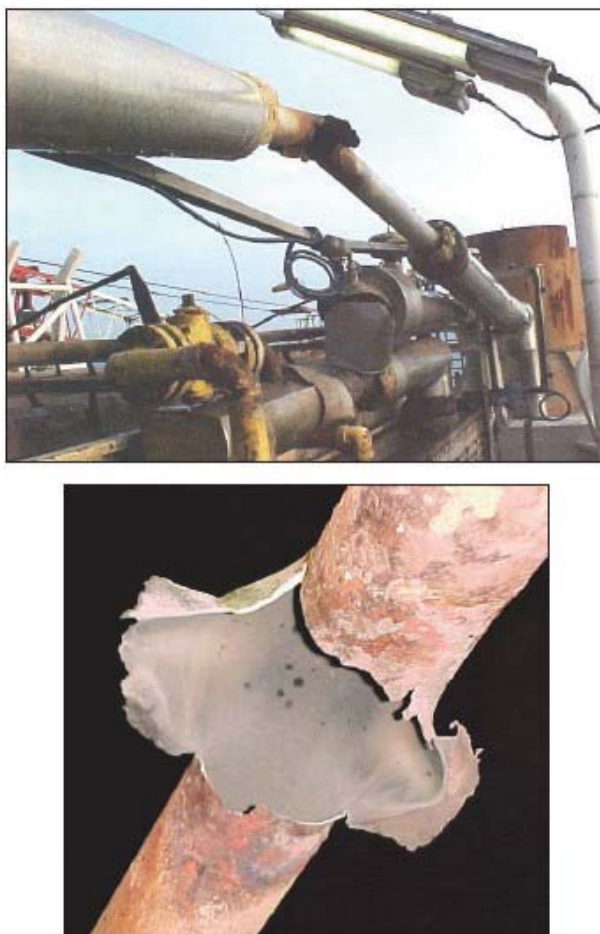


Figure 3—CUI Failure of 4 in. Gas Compressor Recycle Line

Some common areas where breaches in insulation may occur and promote condensation are shown in Table 4.

Table 4—Susceptible Locations for CUI/CUF in Piping Operating Below the Dew Point

Equipment Type	Susceptible Locations
Cold piping	Pipe supports
	Insulation termination areas such as pipe-to-flange locations
	Flanges with stud bolts where insulation bonnets are installed but not sealed
	Piping below flood grade where rising water penetrates the insulation jacketing causing ice lens with swelling that causes jacketing failure
	High foot traffic areas where insulation is degraded by contact with human traffic
	Areas on the insulation jacket showing signs of continual surface condensation or mold
	Holes or cuts in the insulation vapor retarder or jacket
	Ice-to-air interfaces

5.4.3 Pipe Supports

The accumulation of water can occur at locations remote from the point of intrusion, especially in services where the surface temperature does not cause the water to evaporate. For example, this can occur on a horizontal line in the low point of a span between pipe supports, where the insulation is missing at the supports, or there is water ingress due to lack of sealing.

Yet evaporated water may also travel through the insulated system and condense in areas with a lower surface temperature.

There are many process units that operate at temperatures as low as -320°F (-196°C) in chemical plants, refineries, and LNG facilities. In addition to supporting the piping and permitting limited movement, pipe supports in these applications need to be insulated to increase the efficiency of the piping system by not allowing heat to transfer into the process fluids contained in the piping.

Whenever possible, pipe supports should be located outside the insulation system.

5.5 Tankage and Spheres

Susceptible locations for CUI and CUF damage in various equipment types are listed in Table 5. This includes insulated tanks and spheres in both hot and cold service. Examples of CUI and CUF damage in tanks and spheres are shown in Figure 4 and Figure 5.

Table 5—Locations for CUI/CUF in Tanks and Spheres

Equipment Type	Susceptible Locations
Tanks/spheres	Area above chime
	Stairway tread attachments
	Insulation support rings
	Fireproofed legs on spheres (CUF)
	Insulation penetrations such as nozzles, brackets, etc. on shell and roof

5.6 Heat-traced Systems

Heat-traced systems are used to protect pipes from freezing or to maintain process temperatures for piping that transport substances that solidify or lose viscosity at ambient temperatures. Heat-traced systems are divided between electric- and steam-traced systems. From a design perspective, electric-traced systems with chloride-free [i.e. non-polyvinyl chloride (PVC)] electrical insulation would be the preferred choice to minimize CUI damage in insulated systems. Although this may be the preferred choice to minimize CUI damage, in reality, the majority of systems in use today are steam-traced systems.



Figure 4—CUI at an Insulation Support Ring



Figure 5—Failure of Sphere Legs Due to CUF

When steam tracing fails, it defeats all CUI barriers. These systems often fail at coupling joints under the insulation. When steam tracing fails under insulation, it introduces moisture, strips away protective coatings, and raises the metal surface temperature within the CUI temperature regime. In addition, the same conditions can potentially cause ECSCC on austenitic stainless steel pipe and instrument tubing under the insulation. It is good practice to locate heat trace couplings outside the weather jacketing. For insulated equipment that has been idle for an extended period of time, consideration should be given to stripping old insulation for inspection and mitigation before returning it to service.

5.7 Shutdown/Mothballing

Equipment or piping systems that are shut down for extensive periods or mothballed also have higher susceptibility for CUI and CUF damage. During extended idle periods, these weather barriers (i.e. insulation and fireproofing) can deteriorate and lead to increased corrosion. Consideration should be given to removing insulation and fireproofing on equipment and piping systems that are shut down for extended periods of time or as part of the mothballing procedure, especially in moist and humid climates. Fully sealed mesh-reinforced chlorosulfonated polyethylene (CSPE) jacketing systems may be left in place.

6 Insulation and Fireproofing Systems

6.1 Insulation Materials and Thermal Insulative Coatings

6.1.1 General

Thermal insulation is important to facility operations yet is often overlooked and undervalued. These materials can be used in either low- or high-temperature applications. Low-temperature insulations typically include polyurethane, polyisocyanurate, flexible elastomeric foams, cellular glass, and phenolics. These insulation types normally require a vapor barrier under the outer weatherproofing to minimize the potential for condensation of atmospheric moisture. High-temperature insulations typically include perlite, calcium silicate, mineral wool, and cellular glass and fiberglass. For refinery and petrochemical plant applications, insulation materials and thermal insulative coatings can be classified into one of the six categories listed below:

- 1) granular;
- 2) thin blankets;
- 3) fibrous;
- 4) cellular;
- 5) foams;
- 6) thermal insulative coatings.

Table 6 lists the various types that are generally encountered in refining and petrochemical plants, along with the applicable temperature ranges specified for each insulation material in the appropriate ASTM specifications. CUI has been reported under all six types of insulation categories.

Table 6—Various Types of Insulation in Refining and Chemical Plants

Insulation Category	Material (ASTM)	Low Temperature Range		High Temperature Range	
		°F	°C	°F	°C
Granular	Calcium silicate (C533)	80	27	1700	927
	Expanded perlite (C610)	80	27	1200	649
Thin blankets	Silica aerogel (C1728)	−321	−196	1200	649
	Microporous blanket insulation (C1676)	80	27	1200	649
Fibrous	Mineral wool (C547, C553, C592)	NS	NS	1400	760
	Fiberglass (C547)	NS	NS	1000	540
	High-temperature water-resistant stone wool (C547)				
	Type II	NS	NS	1200	649
	Type V	NS	NS	1400	760
Cellular	Cellular glass (C552)	−450	−268	800	427
Foams	Polyurethane	See NOTE	See NOTE	See NOTE	See NOTE
	Polyisocyanurate foam (C591)	−100	−73	250	121
	Elastomeric foam (C534)	−297	−183	250	121
	Polystyrene foam (C578)	−320	−196	165	74
	Phenolic foam (C1126)	−290	−180	257	125
Thermal insulative coatings	Thermal insulative coatings	40	4	500	260
NOTE Check with manufacturer for high and low temperature limits.					

6.1.2 Granular-type Insulations

6.1.2.1 General

Granular insulations are composed of small nodules that contain voids or hollow spaces. These materials are sometimes considered open-cell materials since gases can be transferred between the individual spaces. Calcium silicate and molded perlite insulations are considered granular insulations.

6.1.2.2 Calcium Silicate

Calcium silicate insulation is rigid pipe and block insulation composed principally of calcium silicate that usually incorporates a fibrous reinforcement. It is intended for use in high-temperature applications. If immersed in water at ambient temperatures, the material can absorb significant amounts of water (i.e. up to 400 % by weight). Even when not immersed in water, the material can absorb up to 25 % by weight water in high-humidity conditions because of its hygroscopic nature. Some products are water resistant and will shed bulk surface water if exposed prior to installation of jacketing. When exposed to water, the material has a pH of 9 to 10 and may be detrimental to alkyd or inorganic zinc coatings. Additionally, some manufacturers offer products with controlled or low chloride levels or offer products with corrosion inhibiting chemistries. The advantages and disadvantages for calcium silicate insulation are listed below.

a) Advantages:

- 1) low thermal conductivity;
- 2) available in a variety of shapes/sizes;
- 3) high compressive strength;
- 4) products with corrosion inhibiting chemistry and water resistance are available.

b) Disadvantages:

- 1) will absorb moisture;
- 2) fragile (i.e. brittle) and requires care to avoid breakage during installation;
- 3) chlorides can accumulate in service from the local atmosphere (some newer formulations have chemicals added to minimize this issue).

6.1.2.3 Expanded Perlite

Perlite is a volcanic material containing from 2 % to 5 % encapsulated water. It is a chemically inert substance composed primarily of silicon and aluminum dioxide. The perlite is expanded by means of rapid heating at a temperature between 1475 °F and 2200 °F (800 °C and 1200 °C). The vaporization of the encapsulated water results in the expansion of the perlite particles. These particles have a granular shape.

Expanded perlite insulation, either rigid pipe or block, is composed of expanded perlite, inorganic binders, fibrous reinforcement, and hydrophobic additives. These hydrophobic additives begin to decrease in effectiveness at continuous exposure to temperatures above 400 °F (204 °C). The water resistance of the material is reduced at or above this temperature. Similar to calcium silicate, some manufacturers offer expanded perlite products with controlled or low chloride levels or offer products with corrosion inhibiting chemistries. The advantages and disadvantages for expanded perlite insulation are listed below.

a) Advantages:

- 1) water-resistant up to 400 °F (204 °C);
- 2) good compressive strength;
- 3) available in a variety of shapes/sizes.

b) Disadvantages:

- 1) poor mechanical damage resistance (during handling and transportation);
- 2) more fragile than calcium silicate during installation;
- 3) water resistance will begin to oxidize at 400 °F (204 °C);
- 4) higher thermal conductivity compared to other insulation options.

6.1.3 Thin Blanket Insulations

6.1.3.1 Silica Aerogel

Silica aerogel is comprised of a synthetically produced amorphous silica gel that has had its liquid phase replaced with air; these materials contain no crystalline silica. It is combined with a flexible fiber-based substrate for reinforcement. Due to their nanoporous structure and design, aerogels are strong insulators as they almost nullify convective, conductive, and radiative heat transfer.

a) Advantages:

- 1) low thermal conductivity with reduced required thickness available;
- 2) product form allows for removal and reuse;
- 3) water-resistant up to 500 °F (260 °C);
- 4) wide range of operating temperatures.

b) Disadvantages:

- 1) hydrophobic performance will diminish at temperatures greater than 500 °F (260 °C);
- 2) slow moisture dissipation;
- 3) limitation of product form to wrap and not being available in pipe sizes leads to a nonwater tight system.

6.1.3.2 Microporous Blanket Insulation

Microporous flexible thin blanket insulation is comprised of compacted fumed silica powder with reinforcing fibers, held together with a quilted fabric. This product contains no crystalline silica, requiring minimal PPE to install. These products can be flexible enough to form around 1 in. pipe. The microporous structure gives the insulation low thermal conductivity.

a) Advantages:

- 1) low thermal conductivity results in reduced thickness needed and lower profile;
- 2) hydrophobic surface treatment;
- 3) lightweight;
- 4) fast installation.

b) Disadvantages:

- 1) can be difficult to fabricate around intricate protrusions;
- 2) temperature limited to higher than 75 °F (24 °C);
- 3) hydrophobic performance will diminish at temperatures greater than 600 °F (316 °C).

6.1.4 Fibrous-type Insulations

6.1.4.1 General

This category of insulation materials includes mineral wool and fiberglass (glass wool) insulation. These materials are processed from molten state into fibrous form and combined with organic binders and pressed into rolls or sheets. Fibrous-type insulations are primarily intended for thermal and acoustic insulation; mineral wool and glass wool are also used for fire insulation in construction and industry.

Mineral wool and fiberglass have a lower compressive strength and are typically not considered walkable even under metal jacketing. Typically, upon oxidation of the binder at higher temperatures, the compressive strength of the materials decreases. Unless damaged, this will not impact the thermal performance. Similarly, the efficiency of the hydrophobic additives will be reduced at higher temperatures and under immersion conditions. Mineral wools are unattractive to rodents. (Temperature ranges for fibers, binders, and hydrophobic additives vary and should be verified with the manufacturer.)

6.1.4.2 Mineral Fiber

Mineral wool insulation includes both stone wool and slag wool insulation, which are produced in the same way and comprised essentially the same raw materials, but in different proportions. Manufacturers use a mechanized process to spin a molten composition of stone and slag into high-temperature-resistant fibers. Stone wool insulation is composed principally of fibers manufactured from a combination of aluminosilicate rock (usually basalt), blast furnace slag and limestone or dolomite. Slag is a byproduct from steel production that would otherwise be landfilled.

Mineral wool insulations are vapor permeable. For this reason, mineral wool insulation is always used in combination with other materials for cryogenic applications where condensation can occur. Typically, in these cases the mineral wool is applied not for thermal, but for acoustic purposes. Mineral wool products may reach water resistance through the addition of hydrophobic additives during the fiberization process.

The advantages and disadvantages for mineral wool insulation are as follows.

a) Advantages:

- 1) lower thermal conductivity than calcium silicate and perlite;
- 2) resilient, light weight, and easy to install;
- 3) low leachable chloride content is available (typically <10 ppm);
- 4) open cell structure facilitates moisture dissipation and noise absorption.

b) Disadvantages:

- 1) not suitable for most cryogenic application;
- 2) low static compressive strength;
- 3) chlorides can accumulate in service because of water from the local atmosphere or process leaks.

6.1.4.3 Fiberglass

Fiberglass is composed of pure glass containing various types of binders and is widely used as industrial insulation. Fiberglass has many similarities to mineral wool insulation. The advantages and disadvantages for fiberglass insulation are as follows.

a) Advantages:

- 1) noncombustible;
- 2) light weight;
- 3) easy to install.

b) Disadvantages:

- 1) compressing the material reduces its effectiveness;
- 2) absorbs water.

6.1.4.4 High-temperature Water-resistant Stone Wool

ASTM C547 Type II—High-temperature water-resistant mineral fiber insulation is capable of maintaining water resistance properties up to 482 °F (250 °C), the upper end of the CUI range, while maintaining all other performance characteristics of typical mineral fiber insulation, such as workability (easy to cut and manipulate) and low thermal conductivity. Insulation durability is maintainable up to 1200 °F (649 °C).

ASTM C547 Type V—Another option for high-temperature water-resistant mineral wool, this type of product can offer a denser mineral fiber product than a Type II product that can maintain product integrity up to 1400 °F (760 °C) with the ability to maintain water-resistant properties up to 482 °F (250 °C), the upper end of the CUI range. A Type V mineral fiber product maintains the same advantages and disadvantages of a Type II product.

a) Advantages:

- 1) offers all the advantages of conventional mineral fiber;
- 2) hydrophobic up to 482 °F (250 °C) and water repellency on par with the closed-cell insulation materials.

b) Disadvantages:

- 1) not suitable for most cryogenic application due to fibrous insulations permeability to vapors and condensation issue;
- 2) not recommended for cradle/saddle pipe support areas.

6.1.5 Cellular-type Insulations

6.1.5.1 General

Cellular insulations are classified as either open-cell structures where the cells are interconnecting or closed-cell structures where the cells are sealed from each other. Generally, materials that have greater than 90 % closed-cell content are considered to be closed-cell materials.

6.1.5.2 Cellular Glass

Cellular glass (also referred to as foam glass) is a closed-cell insulation composed predominantly of silica-based glass. It is made by adding powdered carbon to crushed glass and firing the mixture to form a closed-cell structure. It is commonly used on electric-traced or steam-traced piping for freeze protection or process control.

The low permeability and absorption characteristics of cellular glass make it an attractive choice for cold service and cryogenic applications. This insulation material does not wick water or liquids, and is used in hot service where the nonabsorbent/nonwicking properties are desirable. The material has a thermal conductivity rating between mineral wool and calcium silicate and displays good compressive strength. It can be friable and brittle when subjected to mechanical abuse and can crack when subjected to large temperature differences and thermal shock.

Cellular glass has the chemical resistance of glass. The material can suffer vibration-induced damage and can also be prone to damage when boiling water is trapped between the pipe and the insulation. Cellular glass cells may break down over time and trap water. Stress relief cracking of cellular glass can also occur at service temperatures above 450 °F to 500 °F (230 °C to 260 °C). The manufacturer should be consulted for the best method for insulating systems operating above 450 °F (230 °C).

The advantages and disadvantages for cellular glass insulation are as follows.

a) Advantages:

- 1) does not absorb water;
- 2) high resistance to mechanical damage when jacketed;
- 3) thermal conductivity does not deteriorate with aging.

b) Disadvantages:

- 1) susceptible to thermal shock if temperature gradient >300 °F (>150 °C);
- 2) easily abrades in vibrating service and fragile before application;
- 3) difficult to make good joints due to material brittleness and therefore susceptible to moisture ingress through joints;
- 4) moisture under insulation may not dissipate if low points are sealed vapor tight.

6.1.6 Foams

6.1.6.1 General

This category of insulation materials includes polyurethane, polyisocyanurate, flexible elastomeric, polystyrene, and phenolic insulations. Except for flexible elastomeric insulation, they are classified as either rigid/closed-cell foams or flexible/closed-cell foams. Flexible elastomeric insulation is classified as flexible/closed-cell foam. These materials contain chlorides, fluorides, silicates, and sodium ions that can be leached from the insulation at temperatures above 212 °F (100 °C). The leachate produced can have a wide range of pH (i.e. 1.7 to 10). Accelerated corrosion can take place when the pH of the leachate is below 6.

6.1.6.2 Polyurethane Foam

Polyurethane foam is an organic, closed-cellular foam that can be installed by spraying or casting in the shop or field. Precast pieces are also available. Closed-cell foams are structures where all of the tiny foam cells are packed close together with no interconnected pores. The foam cells are filled with a low-

conductivity gas, which helps the foam to rise and expand. Unfortunately, these cells can trap moisture in contact with asset for prolonged periods. It is an insulation product that is typically produced on site and applied by certified applicators. Two liquid components, an organic isocyanate compound (i.e. diisocyanate) and an alcohol (i.e. polyol), are mixed at high or low pressure using a spray gun with the reacting mix being sprayed onto the substrate to provide a seamless seal.

Polyurethane foam is frequently used for preinsulated pipe joints. It has low permeability and absorption characteristics but can absorb water after prolonged service. The advantages and disadvantages for polyurethane foam insulation are as follows.

a) Advantages:

- 1) low permeability and absorption characteristics (closed cell);
- 2) multiple product forms;
- 3) provides a seamless seal.

b) Disadvantages:

- 1) can be ignited and release toxic gases if exposed to an open flame;
- 2) sensitivity to ultraviolet (UV) radiation (sunlight);
- 3) can retain moisture in contact with underlying asset for extended periods;
- 4) can be vulnerable to some acids, caustics, solvents, hydrocarbons, and other chemicals;
- 5) susceptible to long freeze-thaw cycles; cells can break open and become filled with water.

6.1.6.3 Polystyrene Foam

There are two categories of polystyrene foam insulation:

- 1) expanded polystyrene (EPS) foam, and
- 2) extruded polystyrene (XPS) foam.

EPS foam is a closed-cell insulation that is manufactured by expanding a polystyrene polymer. It is usually white and made of pre-expanded polystyrene beads. It is an aromatic, thermoplastic polymer made from the monomer styrene that is in solid (glassy) state at room temperature. When heated above 212 °F (100 °C), it flows sufficiently to permit molding or extrusion, becoming a solid when cooled.

XPS is a rigid, closed-cell insulation manufactured from solid polystyrene crystals. The crystals are fed into an extruder along with special additives and a blowing agent and melted into a viscous plastic fluid. After being forced through the extrusion die, the hot, thick liquid expands to become foam that is shaped, cooled, and trimmed to dimension. This continuous extrusion process produces a uniform closed-cell structure with a smooth continuous skin. EPS and XPS foams are primarily used as a cold system insulation material.

The advantages and disadvantages for polystyrene foam insulation are as follows.

a) Advantages:

- 1) low thermal conductivity;
- 2) high resistance to water and water absorption from freeze-thaw cycling;
- 3) resistant to photolysis.