Corrosion Under Insulation and Fireproofing

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Contents

Contents

Page

Contents

Corrosion Under Insulation and Fireproofing

1 Scope

This recommended practice (RP) 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 RP 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 referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

API 570, *Piping Inspection Code*

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

API Recommended Practice 572, *Inspection Practices for Pressure Vessels*

API Recommended Practice 574, *Inspection Practices for Piping System Components*

API Recommended Practice 575, *Guidelines and Methods for Inspection of Existing Atmospheric and Low-pressure Storage Tanks*

API Recommended Practice 580, *Risk-Based Inspection*

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

API Recommended Practice 653, *Tank Inspection, Repair, Alteration, and Reconstruction*

API Technical Report 938-C, *Use of Duplex Stainless Steels in the Oil Refining Industry*

API Publication 2218, *Fireproofing Practices in Petroleum and Petrochemical Processing Plants*

ASCE 7 [1], *Minimum Design Loads for Buildings and Other Structures*

ASME PCC-2 [2], *Repair of Pressure Equipment and Piping*

ASTM C692-08e1 [3], *Standard Test Method for Evaluating the Influence of Thermal Insulations on External Stress Corrosion Cracking Tendency of Austenitic Stainless Steel*

ASTM C795, *Standard Specification for Thermal Insulation for Use in Contact with Austenitic Stainless Steel*

ASTM C871, *Standard Test Methods for Chemical Analysis of Thermal Insulation Materials for Leachable Chloride, Fluoride, Silicate and Sodium Ions*

ASTM STP 880, *Corrosion of Metals Under Thermal Insulation*

BSI BS 2972 [4], *Methods of test for Inorganic thermal insulating materials*

IMMM EFC 55 [5],*Corrosion-Under-Insulation (CUI) Guidelines*

ISO TS 24817 [6], *Petroleum, petrochemical and natural gas industries—Composite repairs for pipework—Qualification and design, installation, testing and inspection*

NACE SP0198-2010 [7], *Control of Corrosion Under Thermal Insulation and Fireproofing Materials—A Systems Approach*

NFPA 58 [8], *Liquefied Petroleum Gas Code*

OSHA 29 *CFR* Part 1910.1001 [9], *Occupational Safety and Health Standards—Asbestos*

UL 1709 [10], *Rapid Rise Fire Tests of Protection Materials for Structural Steel*

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.

1 American Society of Civil Engineers, 1801 Alexander Bell Dr., Reston, Virginia 20191, www.asce.org.
2 ASME International, 3 Park Avenue, New York, New York 10016-5990, www.asme.org.
3 ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.
4 British Standards Institution, Chiswick High Road, London W4 4AL, United Kingdom, www.bsi-global.com.
5 Institute of Materials, Minerals and Mining, 1 Carlton House Terrace, London SW1Y 5DB, United Kingdom, www.iom3.org.
6 International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland, www.iso.org.
7 NACE International (formerly the National Association of Corrosion Engineers), 1440 South Creek Drive, Houston, Texas 77218-8340, www.nace.org.
8 National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org.
9 U.S. Department of Labor, Occupational Safety and Health Administration, 200 Constitution Avenue, NW, Washington, DC 20210, www.osha.gov.
10 Underwriters Laboratories, 333 Pfingsten Road, North Brook, Illinois 60062, www.ul.com.

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 size below 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.

3.1.8
cladding
See **jacketing**.

3.1.9
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, and digital radiography (DR) detectors.

3.1.10
cold piping
Piping systems normally operating below the dew point.

3.1.11
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.

3.1.12
composite wrap
A wrapping system composed of multiple nonmetallic fiber/polymer layers to repair corroded piping.

3.1.13
corrosion under fireproofing
CUF
Corrosion of piping, pressure vessels, and structural components resulting from water trapped under fireproofing.

3.1.14
corrosion under insulation
CUI
External corrosion of carbon steel 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.

3.1.15
dead-leg
Section of piping of a 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.

3.1.16
deluge system
A network of open sprinklers that are all connected to water main pipe. When activation of the system takes place, all the sprinklers within the hazard zone are activated.

3.1.17
dense concrete fireproofing
Concretes made with Portland cement that can be formed in place or pneumatically sprayed to the required thickness using steel reinforcement.

3.1.18
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.

3.1.19
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.

3.1.20
fireproofing
A systematic process, including materials and the application of materials that provide a degree of fire resistance for protected substrates and assemblies.

3.1.21
fluoroscopy
Real-time X-ray system based on the principal of fluorescing screens.

3.1.22
gadolinium 153
Nuclear isotope that emits gamma radiation.

3.1.23
gamma radiation
Photons or packets of energy emitted from certain nuclear isotopes such as iridium 192 or cobalt 60.

3.1.24
ice lens
A localized zone of ice accumulation.

3.1.25
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.

3.1.26
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.

3.1.27
iridium 192
Nuclear isotope that emits gamma radiation. Used to expose radiographic film.

3.1.28
jacketing
The protective covering that is applied over insulation. Also referred to as **sheathing** or **cladding**.

3.1.29
lagging
Another name for insulation.

3.1.30
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.

3.1.31
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.

3.1.32
mastic
A pasty material used as a protective coating or cement.

3.1.33
mineral fiber
Insulation composed principally of fibers manufactured from rock, slag, or glass, with or without binders.

3.1.34
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.

3.1.35
neutron backscatter testing
A test method that uses high-energy (fast) neutrons to detect the presence of hydrogen atoms.

3.1.36
perlite
Natural volcanic material that is heat expanded to a form used for lightweight concrete aggregate and fireproofing.

3.1.37
photolysis
Chemical decomposition of polystyrene foam caused by light or other electromagnetic radiation.

3.1.38
polyisocyanurate foam
A closed-cell, thermoset, plastic foam formed by combining isocyanurate, polyol, surfactants, catalysts, and blowing agents.

3.1.39
PT
Liquid penetrant examination method.

3.1.40
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.

3.1.41
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.

3.1.42
reliability-centered maintenance
A process used to determine the maintenance requirements of any physical asset in its operating context.

3.1.43
sheathing
See **jacketing**.

3.1.44
structural steel
Steel shaped for use in construction including I-beams, vessel skirts, and saddles for exchangers and other horizontal vessels.

3.1.45
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, intumescents are incorporated to provide an additional insulating layer.

3.1.46
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).

3.1.47
vermiculite
A group of minerals characterized by their ability to expand into long, wormlike strands when heated. This expansion process is called exfoliation.

3.1.48
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
CUI	corrosion under insulation
CUF	corrosion under fireproofing
DR	digital radiography
ECSCC	external chloride stress corrosion cracking
EPS	expanded polystyrene
ET	eddy current examination method
FFS	Fitness-For-Service
GWT	guided wave examination method
IR	infrared imaging
MOC	management of change
NIA	National Insulation Association
NPS	nominal pipe size
OD	outside diameter
PEC	pulsed eddy current examination method
PT	liquid penetrant examination method
PSP	photostimulable phosphor
PSV	pressure safety valve
PVC	polyvinyl chloride
RBI	risk-based inspection
RTR	real-time radiographic examination method
SCC	stress corrosion cracking
SIS	Swedish Standards Institute
SSPC	Steel Structures Painting Council
TSA	thermal spray aluminum
UV	ultraviolet
VT	visual examination method
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 (10 °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 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:

a) duration of the exposure to moisture,

b) frequency of the exposure to moisture,

c) corrosivity of the aqueous environment,

d) condition of protective barriers (e.g. coating and jacketing),

e) equipment design issues,

f) service exposure temperature,

g) insulation type,

h) condition of weather barriers and caulking,

i) type of climate,

j) site maintenance practices,

k) leaking steam-tracing systems,

l) proximity to humidity-causing equipment such as cooling towers,

m) proximity to saltwater, and

n) 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 the moisture contacts the underlying exposed steel 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.

When determining CUI susceptibility, a much broader operating temperature range should be considered, typically from 10 °F to 350 °F (–12 °C to 175 °C) because of fluctuations in operating temperature, ineffective insulation maintenance, 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, though 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 175 °C) although exceptions have been reported at lower temperatures. Below 120 °F (50 °C), it is difficult to concentrate significant amounts of chlorides; while above 350 °F (175 °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. 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.

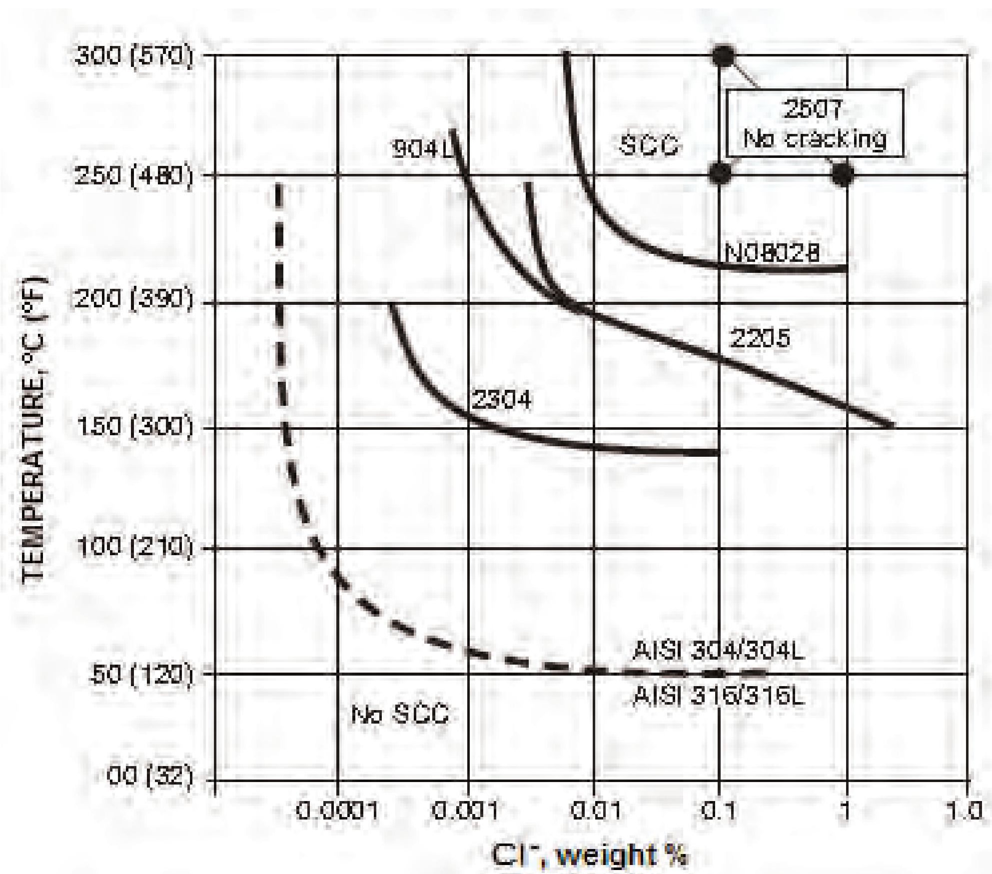


Figure 1—SCC Tendency of Austenitic and Duplex Alloys

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 extinguish 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.

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.

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, and other components
	Areas of protrusions through insulation for equipment/piping operating at or below ambient, or in cold service
	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 (120 °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

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 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 includes process piping, refrigerated piping, piping at or below grade, and pipe supports. Figure 3 shows a CUI failure of piping in a compressor recycle line.

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

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 (–27 °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

Table 3—Susceptible Locations for CUI/CUF in Piping

Equipment Type	Potential Locations
Piping	Dead-legs, vents, and drains
	Pipe hangers and supports
	Valves and fittings
	Bolted on pipe shoes
	Steam-tracing/electric-tracing tubing penetrations
	Termination of insulation at flanges and other piping components
	Carbon/low alloy steel flanges, bolting, and other components in high alloy piping
	Jacketing seams on the top of horizontal piping
	Termination of insulation on vertical piping
	Areas where smaller branch connections intersect larger diameter lines
	Low points in piping with breaches in the insulation
	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

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 middle of a span between pipe supports where the insulation is missing at the supports. 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-tracing 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-PVC) electrical insulation would be the preferred choice to minimize CUI damage in insulated systems. Though 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.

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.

6 Insulation and Fireproofing Systems

6.1 Insulation Materials

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 can be classified into one of the three categories listed below:

— granular,

— fibrous, or

— cellular.

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 three types of insulation categories.

Table 6—Commonly Used Insulation Materials

Insulation Category	Material (ASTM)	Low Temperature Range		High Temperature Range	
		°F	°C	°F	°C
Granular	Calcium silicate (C533)	80	27	1200	650
	Expanded perlite (C610)	80	27	1200	650
	Silica aerogel (C1728)	–321	–197	1200	650
Fibrous	Mineral wool (C547)	0	–18	1800	1000
	Fiberglass (C547)	0	–18	1000	540
Cellular	Cellular glass C552)	–450	–260	800	427
	Polyurethane	See Note	See Note	See Note	See Note
	Polyisocyanurate foam (C591)	–297	–183	300	150
	Elastomeric foam (C534)	–297	–183	250	120
	Polystyrene foam (C578)	–297	–183	165	75
	Phenolic foam (C1126)	–290	–180	257	125
NOTE Check with manufacturer for high and low temperature limits for rigid or sprayed materials.					

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 which 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. 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 for specialty applications. The advantages and disadvantages for calcium silicate insulation are listed below.

— Advantages:

  — low thermal conductivity (when dry),

  — available in a variety of shapes/sizes,

  — available with low chloride levels.

— Disadvantages:

  — will readily absorb moisture,

  — fragile (i.e. brittle) and requires care to avoid breakage during installation,

  — chlorides can accumulate in service because of absorption and evaporation of water from the local atmosphere.

6.1.2.3 Expanded Perlite

Perlite is a volcanic rock containing from 2 % to 5 % bonded water. It is a chemically inert substance composed basically of silica and aluminum. 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 bonded water and the formation of natural glass results in the expansion of the perlite particles. These particles have a granular shape.

Expanded perlite insulation is either rigid pipe or block insulation composed of expanded perlite, inorganic silicate binders, fibrous reinforcement, and silicone water-resistant additions. These silicone additions provide protection from water absorption at temperatures below 600 °F (315 °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 for specialty applications. The advantages and disadvantages for expanded perlite insulation are listed below.

— Advantages:

  — water-resistant up to 400 °F (205 °C),

  — good resistance to mechanical damage,

  — available in a variety of shapes/sizes.

— Disadvantages:

  — more fragile than calcium silicate during installation,

  — higher thermal conductivity than calcium silicate.

6.1.2.4 Silica Aerogel

Silica aerogel is a synthetically produced amorphous silica gel that is distinctly different from crystalline silica. It is impregnated into a nonwoven flexible fabric substrate (i.e. batting) for reinforcement. Aerogels are good thermal insulators because they almost nullify convective, conductive, and radiative heat transfer. Silica aerogels have an extremely low thermal conductivity ranging from 0.03 W/m·K to 0.004 W/m·K that correspond to R-values of 14 to 105 for 3.5 in. thickness. Product forms can be as a flexible mat/blanket and include integral vapor barriers. The advantages and disadvantages for silica aerogel insulation are listed below.

- Advantages:
  - highest thermal performance of any insulating material known,
  - significantly reduced thickness for equivalent performance to other insulating systems,
  - wide range of temperature applications (Note: may require a change in specific product to cover hot or cold insulation).
- Disadvantages:
  - aerogels may be hygroscopic,
  - need chemical treatment to be hydrophobic,
  - typically higher cost of materials (Note: installed cost and performance may provide economic justification).

6.1.3 Cellular-type Insulations

6.1.3.1 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.

6.1.3.2 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 270 °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.

— Advantages:

  — does not absorb water,

  — high resistance to mechanical damage when jacketed,

  — thermal conductivity does not deteriorate with aging.

— Disadvantages:

  — susceptible to thermal shock if temperature gradient >300 °F (>150 °C);

  — easily abrades in vibrating service and fragile before application;

  — higher price when compared to other insulation types.

6.1.3.3 Organic Foams

6.1.3.3.1 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.

6.1.3.3.2 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, usually hydrochlorofluorocarbon, which helps the foam to rise and expand. 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.

— Advantages:

  — low permeability and absorption characteristics (closed cell);

  — multiple product forms and easy to apply in the field;

  — provides a seamless seal.

— Disadvantages:

  — can be ignited and release toxic gases if exposed to an open flame;

  — sensitivity to ultraviolet (UV) radiation (sunlight);

  - can be vulnerable to some acids, caustics, solvents, hydrocarbons, and other chemicals;
  - susceptible to long freeze-thaw cycles; cells can break open and become filled with water.

6.1.3.3.3 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.

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

- Advantages:
  - low thermal conductivity;
  - excellent resistance to water and water absorption from freeze-thaw cycling;
  - very stable and does not biodegrade;
  - resistant to photolysis.
- Disadvantages:
  - like other organic compounds, polystyrene is flammable;
  - when burned without enough oxygen or at lower temperatures, polystyrene can produce a number of chemicals including polycyclic aromatic hydrocarbons, carbon black, and carbon monoxide, as well as styrene monomers, which can irritate eyes, nose, and respiratory system;
  - primarily a cold system insulation material.

6.1.3.3.4 Polyisocyanurate Foam

Polyisocyanurate is an organic, closed-cellular, rigid foam. It has low permeability and absorption characteristics and is typically used in cold service applications. The material is flexible and has reasonable strength to provide resistance to light physical abuse. It has a low thermal conductivity. Disadvantages include combustibility and sensitivity to UV radiation (sunlight). Combustion may release toxic gases. Chemical resistance is generally good but can be vulnerable to some acids, caustics, solvents, hydrocarbons, etc.

The advantages and disadvantages of polyisocyanurate foam insulation are as follows.

— Advantages:

  — low permeability and absorption characteristics;

  — multiple product forms and easy to apply in the field.

— Disadvantages:

  — like other organic compounds, polyisocyanurate is flammable;

  — primarily a cold system insulation material;

  — when burned without enough oxygen or at lower temperatures, a number of chemicals are produced that can irritate eyes, nose, and respiratory system;

  — repeated freeze-thaw cycles can cause cells to break open and become filled with water.

6.1.4 Fibrous-type Insulations

6.1.4.1 General

This category of insulation materials includes mineral wool and fiberglass insulation. These materials are processed from molten state into fibrous form and combined with organic binders and pressed into rolls or sheets. The fiber length, fiber orientation, and type of binder used impact the ability of these materials to repel water. Upon breakdown of the binder, the wicking ability of these materials increases significantly and transmits moisture or corrosive solutions to the underlying surface. Mineral wools are unattractive to rodents but can provide a structure for bacterial growth if allowed to become wet.

6.1.4.2 Mineral Fiber

Mineral fiber insulations are composed principally of fibers manufactured from rock, slag, or glass, with or without binders. Molten glass, stone, or slag is spun into a fiberlike structure. Inorganic rock or slag is the main component (typically 98 %) of stone wool. The remaining 2 % organic content is generally a thermosetting resin binder (an adhesive) and a little oil. Though the individual fibers conduct heat very well, when pressed into rolls and sheets their ability to partition air makes them excellent heat insulators and sound absorbers. Mineral fiber has a lower thermal conductivity than calcium silicate and perlite. However, even with metal jacketing, mineral fiber is subject to mechanical damage because of its low compressive strength and lack of resiliency. This can lead to reduced insulation thickness and possibly open jacket seams where the jacket has been crimped and exposing insulation to moisture. If used at an elevated temperature, the organic binder that helps to hold the fibrous insulation together is burned away causing a further reduction in strength.

Fibrous insulations are readily permeable to vapors and liquids. For this reason, fibrous insulation is not used alone for low temperature applications where condensation can occur. Most fibers can readily wick hydrocarbons and water. Sometimes hydrophobic treatments or coatings are applied to the insulation by manufacturer to reduce water absorption and wicking. These coatings do not eliminate water saturation when immersed, and the coating effectiveness may degrade in service after exposure to higher temperatures.

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

— Advantages:

  — has a lower thermal conductivity than calcium silicate and perlite;

  — low leachable chloride content (<5 ppm).

— Disadvantages:

  — fibrous insulations are readily permeable to vapors and liquids;

  — most fibers can readily wick hydrocarbons and water;

  — mineral fiber is subject to mechanical damage because of its low compressive strength and lack of resiliency;

  — chlorides can accumulate in service because of absorption and evaporation of water from the local atmosphere.

6.1.4.3 Fiberglass

Fiberglass is composed of pure glass containing various types of binders and is widely used as industrial insulation. Fiberglass is mechanically weak like mineral fiber and shares the same disadvantages with respect to wicking and permeability. The advantages and disadvantages for fiberglass insulation are as follows.

— Advantages:

  — noncombustible.

— Disadvantages:

  — compressing the material reduces its effectiveness;

  — absorbs water;

  — can cause skin allergies.

6.2 Insulation Jacketing

6.2.1 General

Regardless of the type of thermal insulation, keeping water out starts with the protective jacketing. In addition, insulation systems should also protect the insulation from mechanical abuse, chemical attack, and fire. The functions performed by insulation jacketing include acting as a:

— barrier to protect the insulation and piping from weather (i.e. rain, snow, sleet, dew, wind, solar radiation, and atmospheric contamination);

— vapor retarder to retard the passage of water vapor into the insulation;

— protective covering to prevent mechanical abuse (i.e. damage) of the insulation system by personnel, machinery, etc.;

— condensate barrier to prevent moisture condensation on the inner surface of the metal jacket (sometimes called moisture retarders).

In many cases, jacketing may perform more than one of the functions listed above. For example, a metallic jacketing may serve as protection from both weather and mechanical abuse.

6.2.2 Jacketing Materials

6.2.2.1 General

Jacketing materials fall into two general categories, namely

1) metallic jacketing and

2) nonmetallic jacketing.

Metal jacketing is the most common jacketing material for insulation.

Metallic jacketing materials include aluminum, steel, and stainless steel. Nonmetallic jacketing materials such as fiber-reinforced plastics and thermoplastics have limited use for jacketing applications because of their low melting temperatures and their lack of resistance to mechanical abuse.

6.2.2.2 Metallic Jacketing

Metal jacketing is supplied as thin sheets and can be smooth, corrugated, or embossed. The inner surface of metallic jacketing may be coated or covered with a moisture-resistant film to retard corrosion of the jacketing. The types of metallic jacketing materials include aluminum, aluminized steel, aluminum-zinc coated steel, galvanized steel, and Type 304 stainless steel. The primary strengths of metallic jacketing are the long service life and the familiarity with its use in refinery and chemical plant applications. The primary weaknesses of metallic jacketing are the difficulty to effectively seal jacketing against moisture ingress and the vulnerability of joints to damage in service (i.e. from foot traffic). When using metal jacketing, it is important to pay attention to draining of the insulation system as a whole and to provide a means of escape for moisture that has entered through the jacketing.

Metal accessories such as banding, fasteners, washers, elbows, etc. for aluminum stainless steel jacketing are typically Type 304 stainless steel, or Type 316 stainless steel for marine applications.

6.2.2.3 Nonmetallic Jacketing

Thermoplastic jackets are made from a variety of thermoplastic materials that include polyvinyl chloride (PVC) and polyvinylidene chloride (PVDC), among others. Most often these materials are used for low-temperature applications. They have a limited application in hydrocarbon plants usage since they have poor resistance to fire. They are used as smooth sheet materials and are often selected in applications where cleanliness is important because they typically have better release properties than metal and are thus more easily cleaned. The plastics also have good resistance to a wide variety of chemicals and are not damaged by water. Nonmetallic jacketing falls into the following two main classes.

a) *Preformed Jacketing*—Preformed nonmetallic jacketing is supplied and applied in sheet form. The sheets are generally made from chlorosulphonated polyethylene synthetic rubber (CSPE). The material may or may not be reinforced with woven glass fiber reinforcement. Provided the appropriate adhesives are used, the material forms water tight joint seals. It is much less prone to damage from foot traffic than metallic jacketing.

b) *Formed-in-place Jacketing*—This type of jacketing is glass fiber reinforced epoxy or polyester applied to the outside of the insulation in an uncured state, and is cured in place to form a rigid jacket. Epoxy jacketing is limited to long straight pipe runs, liquefied natural gas loading lines for example, where factory based application is viable.

Polyester jacketing can be easily formed in the uncured state. The material cures rapidly when exposed to ambient UV light. If necessary, UV lamps can be used to accelerate curing. UV curing polyester jacketing is easily sealed because of good adhesion both to itself and to metallic jacketing overlaps. Once cured, it is resistant to mechanical damage. Expansion/contraction joints may need to be installed to accommodate thermal expansion or contraction of the piping during service to prevent cracking of the material.

Nonmetallic jacketing materials need to be periodically inspected to ensure that the effects of aging are not compromising their fitness for purpose.

6.2.2.4 Jacketing Thickness

The National Insulation Association (NIA) has presented guidelines for jacketing thickness on vessels and storage tanks. These guidelines for vessels are shown in Table 7 and Table 8.

Table 7—NIA Guidelines for Sidewalls on Vertical Vessels

Jacketing Material	Vessel Diameter			
	≤5 ft (1.52 m)	5 ft to ≤10 ft (1.52 m to ≤3.05 m)	10 ft to ≤20 ft (3.05 m to ≤6.10 m)	20 ft to 40 ft (6.10 m to 12.19 m)
Aluminum—smooth rolled	0.016 in. (0.41 mm)	0.016 in. (0.41 mm)	—	—
PVC—smooth rolled [a]	0.030 in. (0.76 mm)	—	—	—
Aluminum—corrugated [b]	—	0.016 in. (0.41 mm)	0.024 in. (0.61 mm)	0.024 in. (0.61 mm)
PVC—corrugated [c]	—	0.050 in. (1.27 mm)	0.050 in. (1.27 mm)	—
Aluminum—galvanized [d]	—	—	—	0.024 in. (0.61 mm)

[a] Secured with minimum 1/2 in. × 0.015 in. (12.7 mm × 0.38 mm) stainless steel banding.

[b] Paneling with 1 1/4 in. (31.75 mm) deep corrugations.

[c] Secured with minimum 1/2 in. × 0.020 in. (19.05 mm × 0.51 mm) stainless steel banding.

[d] Secured with minimum 1 1/4 in. × 0.020 in. (31.75 mm × 0.51 mm) stainless steel banding.

Table 8—NIA Guidelines for Heads on Vertical Vessels

Jacketing Material	Vessel Diameter		
	≤10 ft (≤3.05 m)	10 ft to ≤30 ft (3.05 m to ≤9.14 m)	30 ft to 40 ft (9.14 m to 12.19 m)
Aluminum—smooth rolled	0.024 in. (0.61 mm)	0.024 in. (0.61 mm)	0.032 in. (0.81 mm)
Aluminum—smooth galvanized	0.016 in. (0.41 mm)	0.016 in. (0.41 mm)	0.024 in. (0.61 mm)
Stainless steel—smooth	0.010 in. (0.25 mm)	0.016 in. (0.41 mm)	0.016 in. (0.41 mm)
PVC—smooth	0.040 in. (1.02 mm)	0.050 in. (1.27 mm)	—

Metal jacketing is normally secured with stainless steel bands or screws. PVC jacketing is secured by solvent welding the seams and screws where necessary.

For storage tanks, wind conditions are one of the most critical items to consider when evaluating a jacketing system for large tanks. The tank size usually dictates the type of jacketing to be used over the insulation. Larger tanks require heavier jacketing to overcome high winds on large tank areas. Though developed for buildings and other structures, ASCE 7 provides design information on wind loading that is applicable to vertical wall and roof jacketing on storage tanks.

6.3 Caulking

Caulking is used to seal insulation seams. Caulking is used to create a seal at junctions, terminations, and penetrations in the insulation to prevent the ingress of water. Over time, insulation caulking dries out, cracks, and loses its seal, so it is imperative to inspect for caulking deterioration and renew/replace damaged caulking to prevent moisture ingress.

Once the metal jacketing is applied, the seams are often caulked with a silicone or other type of sealant to prevent the ingress of water through the lap. In addition, there are extremely low permeability rated products such as polyvinylidene chloride resins that lock out oxygen and moisture. It is frequently used on urethane, extruded polystyrene foam, and foam glass because of their excellent vapor barrier properties.

6.4 Fireproofing Materials

6.4.1 General

There are a variety of fireproofing materials, each with their own unique physical and chemical properties. Factors to consider when selecting a material for a fireproofing application include:

a) weight limitations for supports (particularly for heavyweight concrete applications),

b) fire resistance rating (in hours),

c) adhesion strength and durability,

d) ease of application and repair,

e) corrosiveness of the atmosphere,

f) corrosiveness of the fireproofing to the substrate,

g) nonfire operating temperature limitations,

h) anticipated life of the fireproofing material,

i) maintenance requirements,

j) potential for damage during maintenance operations,

k) cost.

A discussion of the various generic types of fireproofing is presented below.

6.4.2 Dense Concrete

Concretes made with Portland cement that have densities between 140 lb/ft^3 and 150 lb/ft^3 (2200 kg/m^3 and 2400 kg/m^3) are considered dense concretes. They can be formed in place or pneumatically sprayed to the required thickness using steel reinforcement. They are durable and can withstand thermal shock from impingement from fire hose streams.

— Advantages:

  — withstands thermal shocks and fire hose streams;

  — withstands flame impingement up to 2000 °F (1100 °C);

  — performance extensively proven (±4 h protection).

— Disadvantages:

  — high weight;

  — high thermal conductivity;

  — installation costly and time consuming.

6.4.3 Lightweight Concrete

Instead of using gravel as aggregate, lightweight concretes use very light aggregate such as vermiculite or perlite with cements that are resistant to high temperatures. Lightweight concretes densities between 25 lb/ft^3 and 80 lb/ft^3 (400 kg/m^3 and 1300 kg/m^3). Though usually applied by pneumatic spraying, they can also be troweled or poured in place. Pneumatically sprayed material is denser than troweled or poured concrete.

— Advantages:

  — lightweight material with better fire protection properties than dense concrete;

  — can withstand flame impingement up to 2000 °F (1100 °C);

  — can withstand thermal shocks and hose streams.

— Disadvantages:

  — porous material;

  — moisture absorption leads to cracking and spalling in freezing climates;

  — more susceptible to mechanical damage than dense concrete.

6.4.4 Other Spray-applied Fire-resistant Materials

6.4.4.1 General

This category of fireproofing materials includes subliming and intumescent mastics, ablative coatings, intumescent epoxy coatings, and inorganic coatings that are spray applied.

— Advantages:

  — lightweight material with better fire protection properties than dense concrete;

  — can withstand flame impingement up to 2000 °F (1100 °C);

  — can withstand thermal shocks and hose streams.

— Disadvantages:

  — porous material;

  — moisture absorption leads to cracking and spalling in freezing climates;

  — more susceptible to mechanical damage than dense concrete.

6.4.4.2 Sprayed Organic Coatings Subliming Mastics/Intumescent Mastics/Ablative Coatings

Sprayed organic coatings are thin when compared to sprayed inorganic coatings. These materials are classified as either intumescent mastics, ablative coatings, or subliming compounds.

Intumescent mastics are normally composed of epoxy-based materials that expand when exposed to fire to form an insulating char with a low thermal conductivity. This insulating char acts as a thermal barrier between the fire and the substrate. During this reaction, toxic fumes and smoke are released at temperatures above 570 °F (300 °C). As a result, intumescent mastics are not suitable for enclosed areas like accommodation modules or temporary safe refuge areas on offshore structures.

Ablative coatings are organic coatings that gradually erode under fire exposure because of the absorbed heat energy from a fire that changes the virgin solid coating into a gas composite. This action prevents heat absorption into the underlying substrate.

Ablative coatings are organic coatings that need large amounts of energy to decompose or break down. They are designed to reduce the rate of burn and usually contain fire retardant chemicals such as aluminum trihydrate or antimony oxide. When exposed to fire, these coatings start to ablate by chemical and physical reactions (i.e. evaporation, chemical cracking, or melting) and in the process consume large amounts of heat energy while keeping the underlying substrate relatively cool for a certain length of time. The gases and vapors generated during the ablative process push oxygen away from the surface, dilute flammable gases preventing them from burning, and interrupt the “chain reaction” of the fire chemically. After decomposition of all organic components, a solid structure of inorganic components remains offering further protection by insulation.

Subliming compounds have an active ingredient that absorbs heat as it changes from the solid to a gas phase (i.e. sublimation). Similar to ablative coatings, subliming compounds are added to provide an additional layer for insulation. The effectiveness of subliming compounds is a function of various elements including the coating material thickness, compounds’ sublimation temperature and enthalpy at sublimation, heat capacity of the substrate, and fire exposure. The fire depletes the subliming compounds. Therefore, once exposed, the protection provided by the compound is reduced or eliminated.

— Advantages:

  — quick application;

  — lightweight;

  — suitable for use on existing supports that may not handle additional weight.

— Disadvantages:

  — can be stripped away by firefighting activities and flash fires;

  — susceptible to abrasion and mechanical damage.

6.4.4.3 Sprayed Intumescent Epoxy Coatings

A wide range of intumescent epoxy coatings are available. These can be described as a mix of thermally reactive chemicals in a specific epoxy matrix formulated for fireproofing applications. Under fire conditions they react to emit gases, which cool the surface while a low-density carbonaceous char is formed. This char then serves as a thermal barrier.

— Advantages:

  — excellent bonding and corrosion protection;

  — lightweight and durable under nonfire conditions;

  — good durability in severe jet fire tests.

— Disadvantages:

  — possible char coating damage during fire if subjected to impingement from fire hose streams;

— requires expertise in application and may require multiple coats or special equipment to apply dual components simultaneously;

— some concerns regarding potential toxicity of gases generated during fire conditions;

— sprayed coatings on loose components, such as valve/actuator covers, require care when handling in freezing conditions.

6.4.4.4 Sprayed Inorganic Coatings

This class of materials is referred to as lightweight cementitious fireproofing materials and is usually based on cement with a lightweight insulating aggregate of exfoliated vermiculite. They provide exceptional dimensional stability under hydrocarbon fire exposure conditions. The exfoliated vermiculite has the capacity to relieve stresses created by both hot and cold thermal shock when subjected to simultaneous exposure to fire and water impingement. These vermiculite cements can perform equally well in multiple fires where no repair or replacements have been carried out.

Vermiculite cements are noncorrosive to the structural or vessel surfaces. They are noncombustible and do not produce toxic fumes during their exposure to fire. Since they are organic, they do not degrade with time. There are examples of applications that have been in service for more than 40 years with little evidence of damage or corrosion to the underlying substrate.

— Advantages:

  — lightweight;

  — vermiculite allows for denting instead of cracking or shattering;

  — noncombustible and nontoxic when exposed to fire.

— Disadvantages:

  — properties vary greatly with composition;

  — not suitable for high-vibration areas

  — great care should be taken to ensure proper application thickness.

6.4.5 Preformed Inorganic Panels or Masonry

6.4.5.1 General

These types of materials for fireproofing are focused on reducing installation costs and time. They also facilitate reductions in weight and overall volume contribution to a structure thereby enhancing the operating efficiency of the equipment.

6.4.5.2 Preformed Inorganic Panels

Preformed, or prefabricated, fireproofing panels are based off many of the attributes commonly associated with intumescent epoxy coatings: ease of application, reduced application times, reduced weight and volume contribution, etc. Yet this form of passive fireproofing stands out on its own if only for the fact that it offers several unique advantages as follows.

- Advantages:
  - reduced tie-in connections/field joints;
  - reduced steel erection costs and damage;
  - lower maintenance costs;
  - installation work unaffected by environmental conditions;
  - easy access for inspection;
  - clean application;
  - no curing time;
  - low thermal conductivity.
- Disadvantages:
  - labor intensive installation when instrumentation/appurtenances attached to columns;
  - susceptible to impact damage.

6.4.5.3 Masonry Blocks and Bricks

This category of insulation materials includes refractory clays and other ceramic materials. These materials are not common for new construction but are present in existing facilities. Advantages and disadvantages for masonry blocks/bricks are shown below.

- Advantages:
  - easy installation,
  - lightweight,
  - availability in a wide array of sizes.
- Disadvantages:
  - high installation costs,
  - high maintenance,
  - admits moisture and cracks through joints in the masonry.

6.4.6 Endothermic Wrap Fireproofing

This flexible, tough, inorganic sheet material with a bonded aluminum foil outer layer is formed from a maximum of inorganic, highly endothermic filler and a minimum of organic binder and fiber. An endothermic wrap when exposed to high temperatures keeps heat out by releasing chemically bound water to cool the outer surface used to protect structural steel, and electrical cable trays/circuits in conduits.

It can be wrapped around a wide variety of potentially exposed vulnerable equipment. These wraps provide electric cable trays with rated performance under ANSI/UL 1709 (or functionally equivalent) conditions. ANSI/UL 1709 covers small- and full-scale test methods to measure the resistance of protective materials to rapid-temperature-rise fires. In most applications, the wrap is held in place by stainless steel bands with foil tape and/or fireproofing caulk on seams, gaps, and termination points. For structural steel in new construction, surface preparation of the substrate should include fresh prime coating to provide corrosion protection.

— Advantages:

  — systems are easily reentered/repaired, allowing retrofitting over steel without dissembling wiring and other attached items;

  — can be applied directly over existing cement or block where additional protection required;

  — flexible endothermic wrap systems are explosion rated.

— Disadvantages:

  — should be weatherproofed or stainless steel-jacketed when used outdoors;

  — weatherproofing should be done with manufacturers specified protection tape to preserve recommended protection.

6.5 Coatings Under Insulation and Fireproofing Systems

6.5.1 General

When moisture penetrates insulation and fireproofing systems, the surface of the underlying component will be subjected to corrosion. In many situations, users apply coatings to the surface of the component before applying insulation or fireproofing. Selecting the right coating is extremely important since the coating is the last line of defense for keeping the electrolyte from the metal surface and preventing corrosion.

6.5.2 Factors to Consider When Selecting a Coating System

There are a variety of issues that should be considered prior to selecting a coating for equipment that will be insulated. These include the following.

— Under dry conditions, what is the maximum exposure temperature for the coating?

— What is the maximum temperature resistance of the coating under immersion conditions?

— What is the minimum level of surface preparation required?

— Is the coating product a single-component or multicomponent product?

— What is the single coat dry film thickness?

— Can the coating be recoated?

— What is the maximum surface temperature?

6.5.3 Coating Systems

Examples of coating systems used under thermal insulation and fireproofing are presented in NACE SP0198. The document discusses the suitable temperature ranges and surface preparation/surface profile requirements for each coating system as well as the suggested prime coat and topcoat for each system. Coatings systems that are often used in these applications include:

— high-build epoxy systems,

— epoxy phenolic systems,

— epoxy novolac systems,

— air-dried or modified silicone systems,

— inorganic copolymer systems or inert multipolymetric coating systems,

— fusion-bonded epoxies,

— thermal spray aluminum (TSA) (with or without a thinned epoxy sealer or silicone coating),

— petrolatum or petroleum wax tape systems.

6.5.4 Surface Preparation

The key element to the long-term performance of a coating system is how well the surface is prepared to receive the coating. Standards for surface preparation have been developed by various organizations including the Steel Structures Painting Council (SSPC), the National Association of Corrosion Engineers (NACE), the Canadian General Standards Board (CGSB), the Swedish Standards Institute (SIS), and the British Standards Institute (BS). A comparison of these standards is shown in Table 9.

Table 9—Comparison of Surface Preparation Standards

System	SSPC	NACE	CGSB	SIS	BS
Solvent clean	SP-1	—	—	—	—
Power tool clean	SP-3	—	31 GP 402	St, 3	—
White-metal blast	SP-5	#1	31 GP 404 Type 1	Sa. 3	BS4232 first quality
Commercial bast	SP-6	#3	31 GP 404 Type 2	Sa. 2	BS4232 third quality
Brush-off blast	SP-7	#4	31 GP 404 Type 3	Sa. 1	Light blast to brush-off
Near-white blast	SP-10	#2	—	Sa. 2 $^1/_2$	BS4232 second quality
Power tool cleaning to bare metal	SP-11	—	—	—	—

For newly installed piping, CUI concerns are frequently addressed by the use of high-quality protective coatings or TSA. However, this solution can be expensive for use in remediation. This high cost of remediation has contributed to the current industry challenges associated with CUI. Therefore, one should consider initial long-term prevention options. This cost and value of an initial prevention option may be assessed using a life cycle analysis based on the remediation method selected. This analysis should consider the remediation costs, the future inspection costs, and the costs associated with loss of containment as the result of failure of the equipment pressure boundary, etc. The surface preparation for the application of most epoxy or metal filled paints can be extensive; some require grit blast to white metal. In some cases the best alternative for remediation is to replace the entire section with new pipe.

For fireproofing, it is important to verify that the external coating is compatible with the fireproofing system.

Since coatings have a finite life, they may need to be renewed periodically to protect equipment and piping from CUI. Inorganic zinc coatings without a topcoating are prone to rapid failure in the presence of moisture. For example, calcium silicate insulated piping, when exposed to water, can generate an environment with a pH of 9 to 10 on the wetted pipe surface. This environment may be detrimental to alkyd and inorganic zinc coatings and can lead to pitting at the joints between the blocks of insulation. Inorganic zinc coatings used without a topcoat on structural steel being fireproofed are generally not effective since zinc is amphoteric. This is because the alkaline conditions beneath concrete and cementitious fireproofing can promote corrosion of the inorganic zinc coating. For carbon and low alloy steels, TSA coating offers superior protection if well applied (see 11.5.4). For stainless steel, aluminium foil wrapping is very effective in protecting the surface from ECSCC. NACE SP0198 provides guidance on the use of protective coatings to mitigate corrosion under thermal insulation and fireproofing materials.

7 Inspection for CUI and CUF Damage

7.1 General

The purpose of the insulation on equipment and piping should be well understood before performing CUI inspections. This can help establish priorities, determine what hazards may exist, determine if insulation can be removed while equipment/lines are in operation, and determine if insulation can be permanently removed. In fact, one of the big benefits from this insulation evaluation process is that it can actually discover many areas do not really require insulation so permanent removal results in 100 % elimination of CUI risk. A management of change (MOC) process should be used when considering modification or removal of any insulation or fireproofing.

As part of an insulation removal evaluation, the following list of questions may be helpful to review prior to executing CUI inspections.

— Is equipment/piping in cyclic service? If yes, what are the maximum temperatures expected and duration of maximum temperature?

— Is equipment/piping in intermittent service? If yes, what is the frequency of operation?

— Is equipment/piping subject to steaming and/or hot gas treatment? If yes, what is the frequency, maximum temperature, and the duration?

— Can the insulation be removed for CUI inspection and remediation while the equipment/piping is in service without adversely affecting process control, product quality, and safety?

— Is equipment/piping currently out-of-service?

— Is insulation installed for the sole purpose of personnel protection (>140 °F)? If yes, can metal cages or ceramic coatings be used instead of insulation?

— Does the equipment/piping contain fluids that may freeze resulting in an interruption of service(s)?

— Does the equipment/piping need insulation for process control/unit production? If yes, would wind and rain guards suffice?

— Does the equipment/piping require heat tracing? If yes, is the heat tracing used continuously or only if certain conditions exist?

— Does the equipment/piping require insulation to reduce condensation?

— Does the equipment/piping require insulation for acoustics?

— Does the equipment/piping require insulation for fire protection or controlling pressure relieving events?

— Do the heat conservation economics dictate this equipment/piping require insulation [usually considered at >200 °F (>95 °C)]?

When assessing the possibility of permanently removing thermal insulation, it may be useful to review the flow chart on the need for insulation presented in IMMM EFC 55.

7.2 Inspection of Piping Operating Below 32 °F (0 °C)

A common source of moisture on piping operating below 32 °F (0 °C) is water vapor penetrating the insulation system where jacketing is damaged or jacket seams and vapor barrier mastics are compromised. Ice may form during operation where water vapor penetrates. Insulated piping and equipment with a layer of ice do not corrode significantly because of the low temperature and limited oxygen concentration. However, the ice-to-air interface provides an ideal location for corrosion to occur as the result of freezing and thawing cycles that can occur as the result of operating condition or periodic shutdowns. The ice-to-air interface (i.e. transition points) should be a focal point of CUI inspections.

In these services, the removal of insulation on operating equipment is undesirable because wet and icy conditions make it difficult to inspect. It also exposes the insulation to atmospheric water vapor, trapping more moisture within the insulation prior to reinsulation of the area. Even though insulation removal is possible with a well-thought-out and well-executed plan to minimize the impact of ice formation, the primary inspection method to consider for these transition points is profile radiography. Profile radiography can be conducted using film, a photostimulable phosphor (PSP) plate, or a digital radiographic system without removing the piping from service. In addition, pulsed eddy current examination method (PEC) can be utilized to assess relative damage in locations where the insulation is not distorted because of ice formation. Any of the inspection methods discussed in 7.3 can be utilized when the piping has been removed from service.

7.3 Inspection Tools and Methods

7.3.1 General

There are both direct and indirect inspection methods for detecting surface corrosion damage (i.e. CUI or CUF) on equipment or structural supports. Direct inspection methods are inspection methods conducted without the presence of a protective barrier (i.e. insulation or fireproofing system). Indirect inspection methods are inspection methods conducted with the protective barrier (i.e. the insulation or fireproofing system) still in place. A discussion of all inspection methods is presented below along with the advantages and disadvantages of each method.

7.3.2 Direct Inspection Methods

7.3.2.1 Visual Examination Method (VT) with Complete Removal of Insulation/Fireproofing

The most reliable method to detect CUI and CUF on carbon and low alloy steel systems is to physically remove the insulation or fireproofing and visually inspect the surface for damage. This approach is costly since insulation or fireproofing on equipment or structural supports (i.e. I-beams, vessel skirts, etc.) has to be stripped and reinstalled. Scaffolding costs to access insulated areas being inspected can be significant especially for large vessels or piping systems on columns or towers. Scaffolding costs can be reduced in some situations utilizing rope access-qualified inspectors. Inspection personnel need to be careful to avoid contact with surfaces at or above 140 °F (60 °C).

— Advantages:

  — only method that can detect 100 % of all surface corrosion damage.

— Disadvantages:

  — expensive because costs have to be incurred for removing and reinstalling insulation/fireproofing on equipment or structural components (Note: additional costs are incurred if scaffolding is required to access insulated surfaces);

  — special precautions are necessary on asbestos insulated systems;

- process problems may occur if the insulation is removed while the piping is in service;
- personnel may be exposed to hot surfaces.

7.3.2.2 Liquid Penetrant Examination Method (PT)

Typically, ECSCC on insulated stainless steel equipment is not normally detected until leakage occurs. When this occurs, inspection of the area using PT is an effective way of determining the extent of damage (i.e. cracking) on austenitic and duplex stainless steel. Damage is often associated with the weld heat affected zone.

Liquid penetrant examination is generally limited to surface temperatures below 120 °F (49 °C). After cleaning of the surface being inspected, the penetrant is applied and allowed to reside on the surface for a period of time for capillary action to draw the liquid into the crack. Excess penetrant is then removed from the surface and dried, and an absorbent, light-colored powdered material (referred to as a developer) is applied over the inspection area. The developer acts as a blotter, drawing any penetrant liquid present within cracks to the surface. As a result of the penetrant being drawn out, visible discolored streaks are produced plainly delineating the cracks. The inspector then can observe the indications against the background of the developing powder.

Advantages and disadvantages of liquid penetrant inspection with partial insulation removal or at inspection ports are as follows.

- Advantages:
  - capable of detecting very small discontinuities;
  - relatively inexpensive nonsophisticated equipment.
- Disadvantages:
  - surfaces have to be clean and free of organic or inorganic contaminants that can impede the action of the penetrating media;
  - when sprayed, penetrants are easy to ignite when exposed to ignition sources;
  - cold surfaces require longer dwell times to allow sufficient time for penetrant to be drawn into the crack.

7.3.3 Indirect Inspection Methods

7.3.3.1 General

Indirect inspection methods can be classified as semiquantitative methods that attempt to estimate the relative degree of surface corrosion damage present or as qualitative methods that attempt to look for the impact that surface corrosion damage has on the insulation/fireproofed system.

7.3.3.2 Semiquantitative Methods

7.3.3.2.1 General

These are inspection methods that indirectly quantify the relative degree of surface corrosion that has occurred. These methods are conducted without complete removal of the insulation or fireproofing from the equipment or structural support and include ultrasonic, radiographic, eddy current, or thermal inspection methods.

7.3.3.2.2 Guided Wave Examination Method (GWT)

GWT can be used to detect CUI on piping. This testing can be performed without the requirement of extensive insulation removal. It can also provide inspection coverage over long distances under the right circumstances. GWT utilizes an array of low-frequency ultrasonic transducers, attached to the pipe circumference of a pipe, to generate an axially symmetric wave in both directions away from the transducer array. These transducer arrays can generate either torsional, flexural, or longitudinal waves. Figure 6 shows examples of guided wave equipment and signal displays.

The torsional wave mode is the transmission mode most commonly used. The equipment operates in a pulse-echo configuration where the array of transducers is used for both the excitation and detection of the signals.

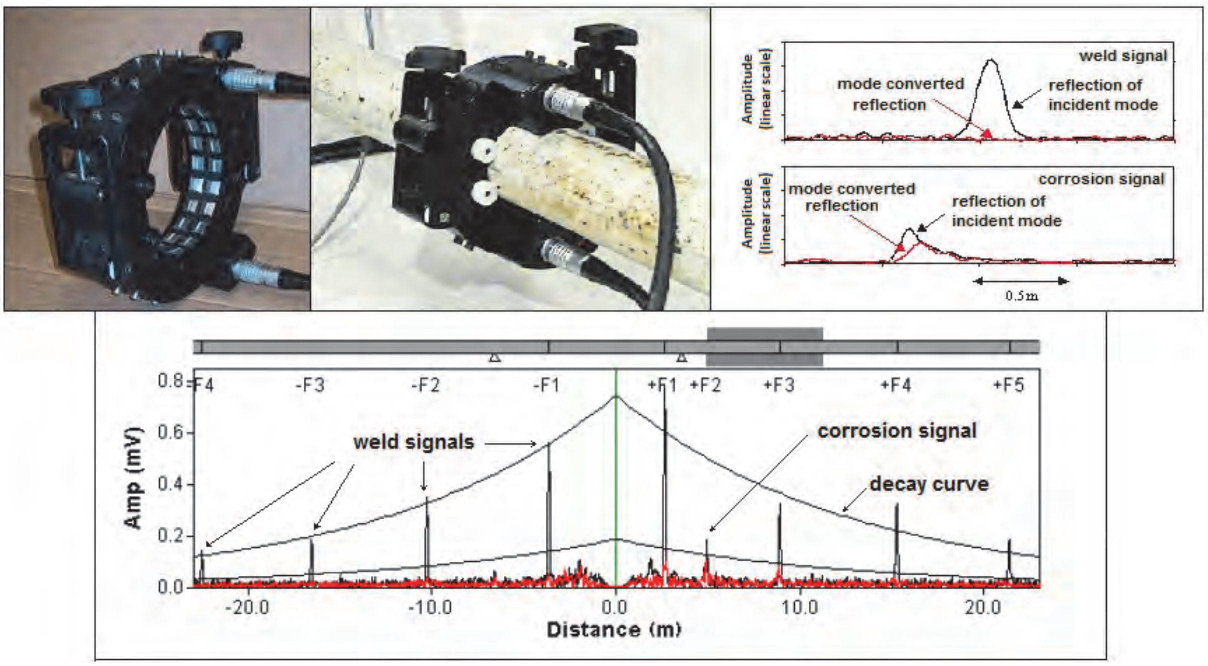


Figure 6—Guided Wave Transducer Arrays, Signal Representation, and Results

GWT can be used as a screening method to identify potential areas of CUI damage. Testing can be performed without widespread removal of the insulation system (i.e. jacketing and insulation).

Factors that limit the effectiveness of GWT include excessive internal or external surface roughness, exterior connections such as welded pipe supports, high viscosity liquids in the piping, and soil in direct contact with the exterior of the piping system. Inspection coverage is also limited by the number of welds and elbows in the piping system. Also, defects located in the immediate vicinity of welds are difficult to identify because of the strong ultrasonic reflection from the weld itself and could be as much as 6 in. (150 mm) on either side of the weld. This method cannot detect localized pits and typically requires corrosion damage be greater than 4 % to 10 % of the pipe cross section to be detected. As a result, this method of inspection may not be applicable if CUI damage is not extensive.

In addition to the limitations discussed above, it should be noted that interpretation of data is operator dependent. Owner/users should review the experience of operators performing GWT on piping systems prior to conducting an inspection. Some owner/users have required performance demonstration tests prior to initiating an extensive GWT program. Advantages and disadvantages for guided wave testing are shown below.

- Advantages:
  - can inspect up to 100 ft (30 m) in each direction away from the transducer array;

— only ~3 ft (1 m) of insulation need to be removed to attach transducer array;

— piping from 2 to 48 NPS can be tested.

— Disadvantages:

— limited to applications operating below 250 °F (125 °C);

— piping containing high-viscosity liquids, heavy external coatings, buried piping, or piping with an excessive number of welds/fittings can reduce the extent of inspection coverage;

— isolated pitting or corrosion in the immediate vicinity of welds may not be detected;

— technique is operator dependent.

7.3.3.2.3 Radiographic Examination Methods

There are a variety of techniques involving radiographic methods that can be used to detect CUI damage. Radiography essentially requires a source of radiation opposite a detection medium that records the radiation either as a film or digital image. These include profile radiography, film density radiography, flash radiography, radiometric profiling, real-time radiography, computed radiography (CR), and digital radiography (DR). A discussion of each method is presented below along with their advantages and disadvantages.

a) *Profile Radiography*—Profile radiography is used to radiograph a small section of the pipe wall. A comparator ball is used to assess the remaining wall thickness of the pipe (see Figure 7). The exposure source is usually iridium 192, with cobalt 60 being used for heavier wall piping. Alternately, profile radiography can also be done using X-ray sources. Profile radiography is an effective evaluation method but becomes technically challenging in piping systems over 10 in. (25.4 cm) in diameter and only offers the limited luxury of verifying relatively small areas. Profile radiographs can be taken using either a tangential or double-wall radiographic technique.

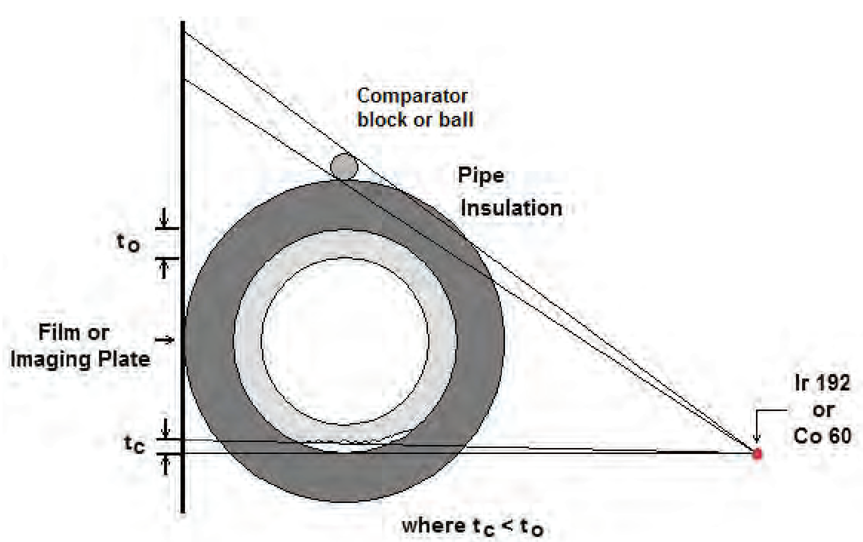


Figure 7—Schematic of Profile Radiography Setup

This technique is not capable of detecting ECSCC on austenitic or duplex stainless steels. In addition, radiation safety can be a real concern. The need to cordon off a large area for radiographic examination can result in downtime and personnel scheduling conflicts. Profile radiography is usually preferred to assess insulated piping for uniform corrosion damage. Figure 8 shows a profile radiograph image made using a digital imaging plate.

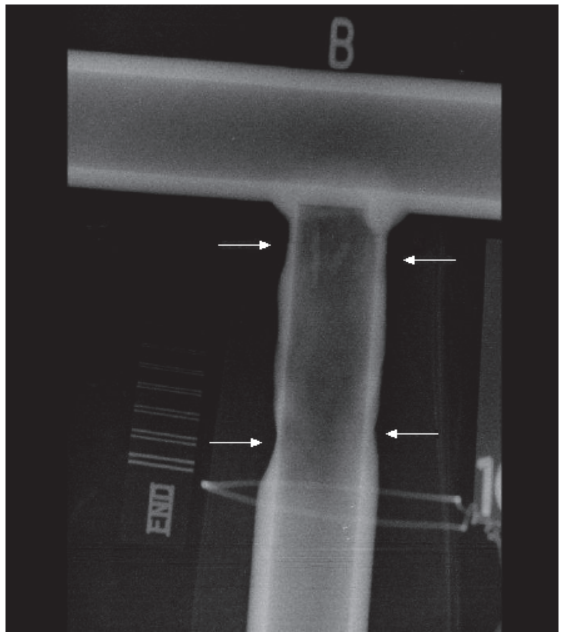


Figure 8—Profile Radiograph of CUI Damage on an Insulated Small Diameter Pipe

When pitting damage is perpendicular to the axis of the radiographic beam, the pit depth measurement can be measured directly off the radiograph [see Figure 9 a)]. When the pitting is located at some angle to the axis of the radiographic beam, the projected pit depth (h) needs to be corrected for the geometry [see Figure 9 b)]. Guidelines on the application limits for profile radiography are shown in Figure 10.

The advantages and disadvantages of profile radiography are as follows.

- Advantages:
  - exposes a small section of pipe to tangential radiation and compares the image dimensions with that of a comparator of known size, which gives the wall thickness;
  - used routinely on piping 2 NPS and above;
  - determines wall thickness with an accuracy smaller than ±0.040 in. (±1 mm).
- Disadvantages:
  - limitations on pipe size that can be inspected.

b) *Film Density Radiography*—Profile radiography and film density radiography are complementary methods. Film density radiography is preferred to assess pitting corrosion damage on insulated piping because of the difficulty of aligning pits perpendicular to the radiographic beam in profile radiography. Film density radiography only measures the average wall thickness (AWT) of the piping and is often used on small diameter piping [i.e. ≤6 in. (150 mm)]; however, with some trade-offs, this technique can be used on larger diameter piping.

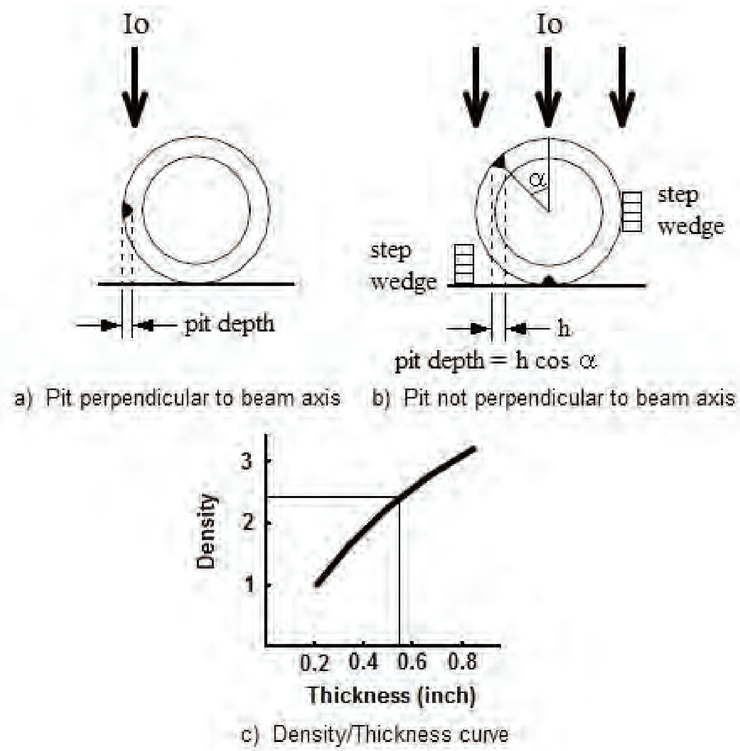


Figure 9—Pit Depth Measurement Techniques

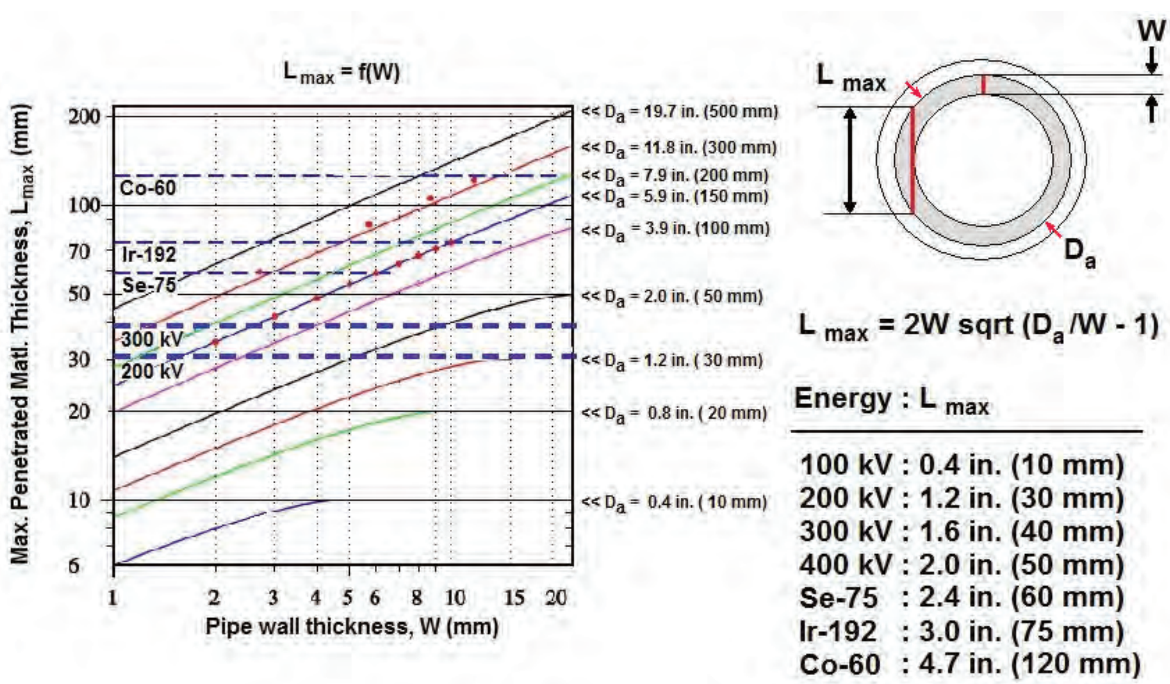


Figure 10—Application Limits for Tangential and Film Density Radiography

The appropriate energy and film speed should be chosen when the film density measurement technique is utilized to achieve good image quality. It is important to locate the pit or local corrosion area correctly. The pitting should lie on film side during exposure to prevent an underestimation of its depth. The depth of the pitting and remaining wall thickness can be determined using the measured density of the pit and sound wall and a density/thickness reference curve [Figure 9 c)]. The density/thickness reference curve should be developed using step wedges that are made from material that is radiographically similar to the piping being evaluated. The step wedge thickness should be twice the thickness of the pipe wall being evaluated. Advantages and disadvantages of film density radiography are as follows.

— Advantages:

  — technique can locate irregular or scattered pits;

  — provides a permanent record of examined areas;

  — provides a relatively easy scanning method without the need for insulation removal.

— Disadvantages:

  — corrosion products within pits can decrease film density and result in an incorrect determination of the wall thickness;

  — liquids present in the equipment (piping) will reduce the transmitted radiation;

  — an ultrasonic examination will also be required if density curves are not calculated;

  — piping or equipment would require insulation to protect the film at elevated temperatures.

Film density radiography can also be done using either CR or DR.

c) *Flash Radiography*—Flash radiography is an alternative to conventional gamma radiography. It is normally applied to pipes up to 12 in. outside diameter (OD) to detect corrosion on pipe ODs under insulation. It can be applied to items with diameters up to 36 in. (1 m) given sufficient source to film distance and radiation output. This technique utilizes a field portable X-ray tube rather than a radioactive source.

The devices are capable of producing through wall images for insulated piping up to 2 in. (50 mm) in diameter and for pipes up to 12 in. (300 mm) in diameter to detect corrosion on the OD of insulated piping. The technique uses X-ray equipment with a low radiation exposure time, fast X-ray films and intensifying screens, or digital detection media. The beam is arranged tangentially to the pipe wall and corrosion of the external wall shows up as a variation in the profile of the pipe. It saves costs normally attributed to the removal and reinstatement of insulation.

Flash radiography can also identify where insulation has become waterlogged. Image contrast, image resolution, and the penetrating ability of flash radiography are not as good as that for conventional radiography because of the limited radiation available, the large grain film, and the relatively large focal spot of the sources. Despite this, the image quality is sufficient to detect significant metal loss on the OD of insulated pipe.

Figure 11 shows an example of a flash radiography system for pipe profiling to detect wall thinning due to corrosion. Advantages and disadvantages of flash radiography are as follows.

— Advantages:

  — no need to rope off an exclusion area because of the low radiation available;

  — can identify water-logged insulation.

Figure 11—Photo of a Flash Radiography System for Pipe Profiling to Detect Wall Thinning Due to Corrosion

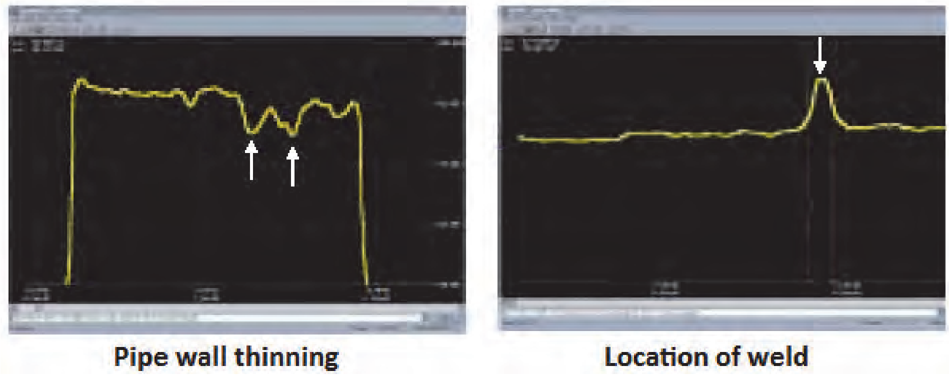
- Disadvantages:
  - inspection generally limited to pipe diameters up to 12 NPS;
  - image contrast and resolution not as good as conventional radiography because of the limited radiation available, the use of large grain film, and the relatively large focal spot of the devices.

d) *Radiometric Profiling*—These handheld radiographic systems use a gadolinium 153 radioactive source in combination with a solid state scintillator that converts X-rays into photons (see Figure 12). The activity of the source and the length of the C-arm used determine the maximum density that the equipment can penetrate when looking for CUI. This equipment can allow estimation of the pipe wall thickness when shot through the center of the pipe. The limitations with regard to pipe and insulation diameter depends on the product inside the pipe, the density of the pipe material (thickness), the type of insulation, and the type of insulation jacketing being penetrated. In general, this equipment is capable of inspecting insulated standard wall thickness pipe with an overall OD of up to 24 in.

Advantages and disadvantages of radiometric profiling are as follows.

- Advantages:
  - suitable for piping from 1/2 to 24 NPS;
  - no radiation barricade is required to utilize device;
  - very portable and may be operated by a single technician.
- Disadvantages:
  - measures the remaining combined double-wall thickness, not the pipe wall thickness of the corroded area;
  - cannot differentiate between ID and OD corrosion;
  - requires a radioactive materials license.

e) *Real-time Radiographic Examination Method (RTR)*—RTR, commonly referred to as fluoroscopy, provides a clear view of the pipe's OD through the insulation, producing a silhouette of the OD of the pipe on a TV-type monitor that is viewed during the inspection [see Figure 13 a)]. No film is used or developed. The real-time device has a radiation source and image intensifier/detector that are connected to a C-arm [Figure 13 b)]. There are two categories of real-time radiography devices, one using an X-ray source and one using a gadolinium radioactive isotope (i.e. Ga-153) source. Each has its own advantages and disadvantages; however, the X-ray systems deliver far better resolution than the isotope systems.



a) Display Showing Double-wall Thickness

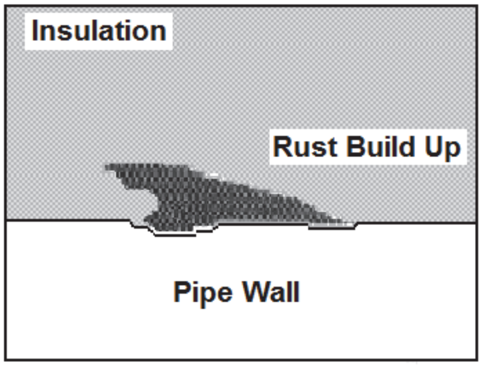
b) Photo of a Radiometric Profiling System

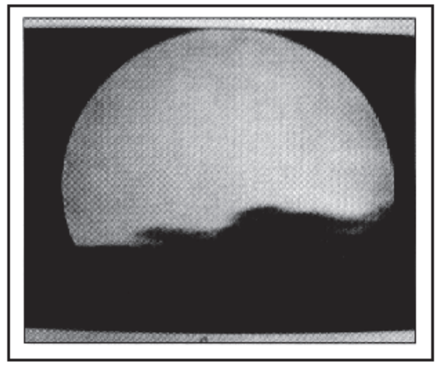
Figure 12—Radiometric Profiling Display and System

The X-ray digital fluoroscopy equipment operates using a low-level radiation source (≤75 KV). The equipment allows the voltage and/or amperage to be adjusted to obtain the clearest image and allows for safe operation without disruption in operating units or even confined spaces. As a result of the low-level radiation, the radiation does not penetrate the pipe wall. Instead, the radiation penetrates the insulation, and images the profile of the outer wall of the pipe. In order for CUI to be detected on insulated pipe, it may be necessary to rotate the fluoroscopy device 360° around a pipe. In many instances, the image may indicate a rough surface of the OD of the pipe indicative of corrosion; however, other means should be employed to determine the extent or degree of corrosion present.

Since the radiation is generated electrically, the instrument is perfectly safe when the power is off. Equipment utilizing radioactive material requires additional precautions to ensure the source is shielded when not being used. These precautions extend to transportation and storage of radioactive material in accordance with NRC or state mandated regulations.

Most of the fluoroscopy systems come with a heads-up video display. A helmet-mounted, visor-type video display frees the system operator's hands to maneuver the C-arm while keeping the image before the operator at all times. The heads-up display also improves interpretation by shielding the screen from the sun. The video images can be printed on site using a video printer or recorded for evaluation at a later date.





a) Representation of CUI (left) and a Silhouette Display of CUI (right)

b) Photo of a Real-time Radiography System

Figure 13—RTR Display and System

Advantages and disadvantages for real-time radiography are shown below.

— Advantages:

  — images are easily viewed because they are digital and can be electronically stored and retrieved using a computer;

  — there is no maximum size limitation since multiple arrays can be assembled to view large areas.

— Disadvantages:

  — adequate clearance [i.e. up to 12 in. (30 cm)] required on piping in congested areas;

  — wet insulation hampers testing;

  — radioisotope system image quality deteriorates as isotope decays.

f) *Computed and Digital Radiography*—Film radiography is the dominant, volumetric nondestructive testing technique used throughout the world. The primary advantages of film radiography are that film is lightweight, flexible, and used in a variety of applications for many years with a proven track record. Despite this, film does have disadvantages. Namely, film processing requires significant amounts of time to develop radiographs (~20 minutes), specialized facilities for film processing (i.e. a dark room), and generates hazardous wastes that require disposal (namely, silver thiosulfate). Film radiographs have a limited shelf life, and require a temperature- and humidity-controlled storage environment. By contrast, DR requires none of the above. Digital images can be generated, optimized, analyzed, stored, and distributed in electronic format.

1) *Computed Radiography (CR)*—CR is a transitional technology between film and direct DR. A reusable, flexible, PSP plate is loaded into a cassette and is exposed in a manner similar to traditional film radiography. The cassette is then placed in a laser reader where it is scanned and translated into a digital image. Depending on the resolution required and image size, the process of digitizing may take from one to five minutes. Once digitally captured, the image may be stored on a computer or other electronic media. Archiving is made easier and the images can be electronically distributed to others for viewing. Advantages and disadvantages for CR are shown below.

— Advantages:

  — no silver based film or chemicals are required to process film;

  — reduced film storage costs because images can be stored digitally;

  — requires fewer retakes due to underexposure or overexposure.

— Disadvantages:

  — imaging plates can be damaged by rough handling.

2) *Digital Radiography (DR)*—A direct DR system is different from CR in that it digitizes the photon radiation that passes through an object directly into an image that can be displayed on a computer monitor. There are three technologies used in direct digital imaging systems:

— amorphous silicon devices,

— charge coupled devices, and

— complementary metal oxide semiconductor devices.

Direct digital system images are available for viewing and analysis in seconds as compared to the minutes required in CR systems. The increased processing speed is a result of the unique construction of the pixels in a direct digital system, an arrangement that also allows an image resolution that is superior to CR and most film applications.

Advantages and disadvantages for DR are shown below.

— Advantages:

  — requires less radiation to produce an image compared to film radiography;

  — the image may be stored, emailed, or processed on a computer;

  — automated defect recognition systems can be used to analyze the image, replacing the subjective assessment of an inspector.

— Disadvantages:

  — DR panel detectors require care to avoid damage;

  — lifetime of DR panel detectors dependent on duty cycle/doses applied;

  — as a result of manufacturing, every DR panel has some dead pixels.

7.3.3.2.4 Pulsed Eddy Current Method (PEC)

PEC has been used in recent years to detect areas of wall thinning on insulated piping through aluminum or stainless steel jacketing. It is also used to inspect fireproofed legs on storage spheres. It is a noncontact, electromagnetic examination method used to detect the average wall loss of carbon and low alloy steel materials. A photo of a pulsed eddy current system is shown in Figure 14.

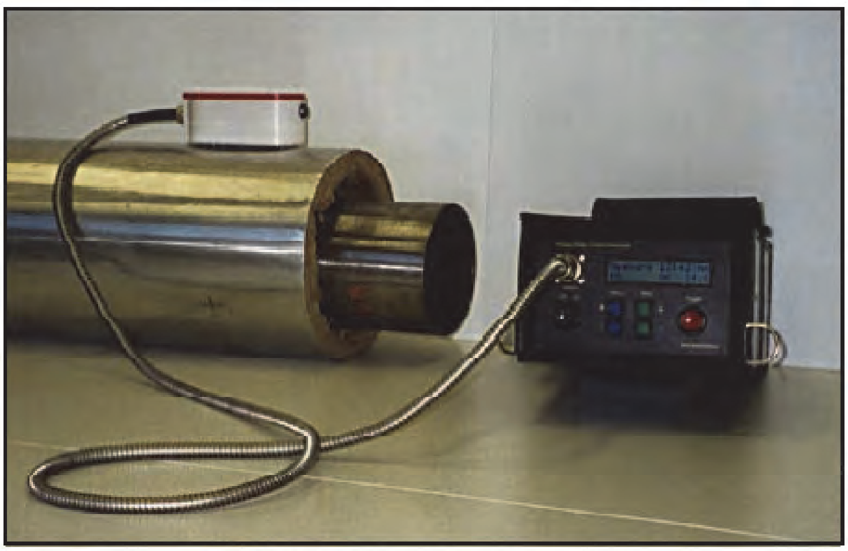


Figure 14—A Pulsed Eddy Current Instrument with Probe

A magnetic field, created by an electrical current in the probe coil, penetrates the jacketing and magnetizes the pipe wall. Current, in the probe coil, is then switched off to cause a sudden drop in the magnetic field. As a result of the change in the magnetic field, eddy currents are generated in the pipe wall. These eddy currents diffuse inward and decrease in strength. This decrease in the strength of the generated eddy currents is monitored by the probe coil. The thickness of the component is related to the length of time it takes for the eddy currents to show a change of the decay rate when eddy currents reach the back wall of the metal. The greater the wall thickness of the component, the longer it takes for the eddy currents to reach the backwall. Figure 15 and Figure 16 show a representation of the pulsed eddy current technique and a pulsed eddy current display.

The area where the measurement is taken is referred to as the “footprint.” The probe is designed in such a way that the magnetic field focuses on an area on the surface of the component. The thickness measured by the technique is the AWT over the footprint area. The size of the area is dependent on the insulation, component thickness, and probe design. In general, the footprint can be considered to be on the order of the insulation thickness. Since the technique measures the average rather than the minimum thickness component thickness, the technique is not suitable to detect pitting that can be highly localized. This effect is shown in Figure 17.

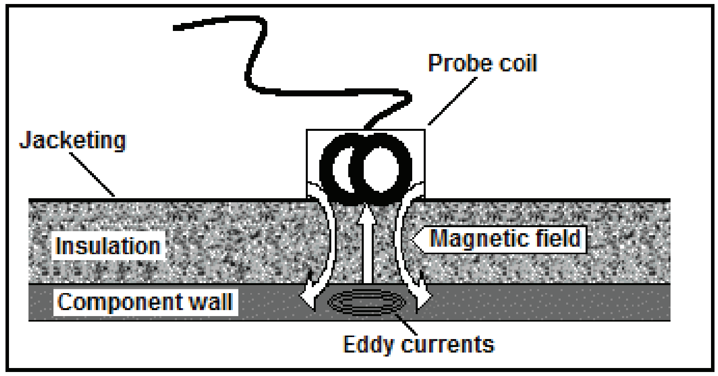


Figure 15—Principle of Operation the Pulsed Eddy Current Technique

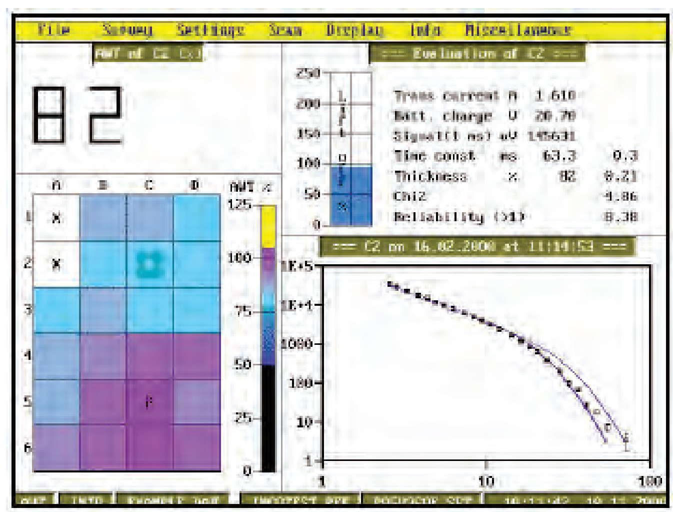


Figure 16—A PEC Display Showing AWT Reading (top left), Logged Inspection Grid (bottom left), and the Decay of the Eddy Currents (bottom right)

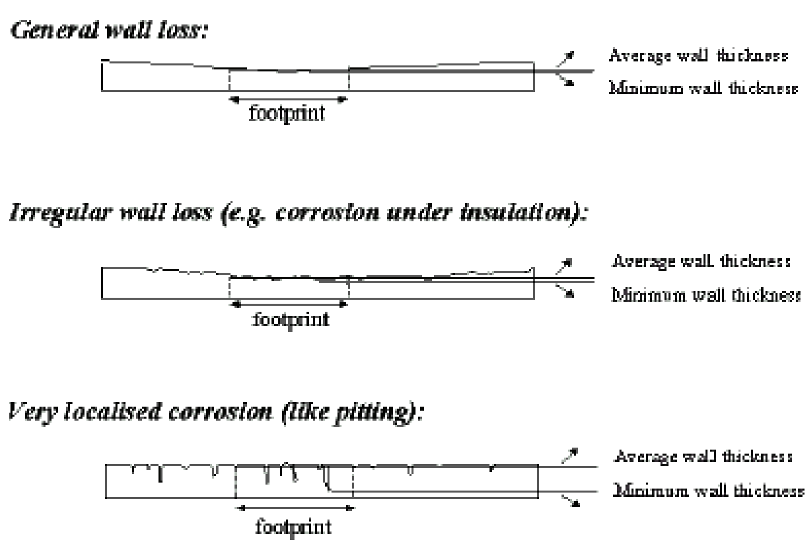


Figure 17—Difference Between Average and Minimum Wall Thickness Within the Footprint

PEC can be used on carbon and low alloy steel equipment and piping through up to 8 in. (200 mm) of insulation and jacketing. The advantages and disadvantages for pulsed eddy current inspection are shown below.

- Advantages:
  - noninvasive, noncontact method that does not require surface preparation;
  - can be used between –150 °F and 930 °F (–100 °C and 550 °C).
- Disadvantages:
  - averages corrosion over a 4 in. (100 mm) diameter area so that isolated pitting may be difficult to detect;
  - affected by ferromagnetic appurtenances such as insulation rings, vents, and drains that can obscure surface damage;
  - technique is operator dependent;
  - cannot be used on insulated systems with galvanized or aluminized steel jacketing.

7.3.3.3 Qualitative Methods

7.3.3.3.1 General

These are inspection methods that attempt to assess the quality of the insulation/fireproofing system as an indirect measure of the potential for surface corrosion damage. These methods are conducted without removing the insulation or fireproofing from the equipment or structural support and include the visual inspection with partial removal of the insulation, the neutron backscatter, and thermal/infrared inspection methods.

7.3.3.3.2 Visual Examination Method (VT) with Partial Removal of Insulation

The most reliable technique to detect CUI is to physically remove the insulation and visually inspect the surface of the vessel or piping. This approach is costly since equipment must be deinsulated and reinsulated and frequently requires scaffolding to access areas for inspection. Removing smaller sections of insulation (i.e. windows) is useful for advanced inspections to help prioritize equipment for remediation or more thorough follow-up inspections.

The placement and size of these inspection windows (i.e. holes cut in the insulation to expose the equipment external surface for inspection) is very important. Windows should be cut where CUI is most likely such as at poorly sealed insulation penetrations, at low points in the piping system where water can collect, at insulation support rings or vessel stiffening rings, or at areas where the insulation jacketing is in poor condition and water can penetrate the insulation system. The areas where insulation is removed should be large enough to be representative of the condition of the equipment. It may be necessary to cut several windows in suspect locations because of the difficulty in predicting where CUI damage has occurred.

For example, on a large drum or tower it may be necessary to remove a vertical strip of insulation to represent different temperature zones in the equipment and to locate stiffener or insulation support rings. Once located, specific insulation support rings or stiffeners may then be selected for insulation removal around the circumference of the vessel to locate areas where degradation may be the most severe.

A variant of partial insulation removal is to perform visual examination at inspection ports in the insulation. This approach is of minimal value because of the limited amount of surface area exposed for inspection.

Advantages and disadvantages of visual inspection with partial insulation removal or at inspection ports are as follows.

- Advantages:

    — costs associated with insulation removal/reinstallation are significantly reduced compared to complete removal of insulation;

    — limited exposure to hot surfaces for personnel.

— Disadvantages:

    — CUI damage can be missed since only a limited area of the equipment is inspected;

    — special precautions are necessary on asbestos insulated systems;

    — windows cut in insulation pose a potential leak path for water ingress if insulation not effectively repaired/sealed.

7.3.3.3.3 Neutron Backscatter Examination Method

The neutron backscatter technique works because of the interaction of neutrons with hydrogen atoms. The technique utilizes an americium 241 radioactive source to emit fast neutrons with high energies through the insulation jacketing. When these fast neutrons interact with hydrogen atoms, they release energy and are transformed into slow or thermal neutrons. The thermal neutrons are scattered in all directions, but have a short travel path. Some of these thermal neutrons are scattered back toward the scanning head and counted by a sensitive detector. The more hydrogen atoms present in a material, the more thermal neutrons produced and counted by the detector. Figure 18 shows a photo of a neutron backscatter system.

It should be noted that this technique detects hydrogen atoms. Therefore, these devices cannot distinguish between water, hydrocarbons, acids, bases, and organic liquids. However, the presence of any of these fluids would warrant follow-up inspection.

Advantages and disadvantages for the neutron backscatter inspection method are as follows.

— Advantages:

    — detects the presence of water or hydrocarbon under insulation jacketing;

    — easy-to-use method that can be used to rapidly scan insulated surfaces.

— Disadvantages:

    — detects the presence of water or hydrocarbon in the insulation system, not corrosion;

    — technique is only effective while insulation is wet; technique is not effective if sufficient time has elapsed for insulation to dry out.

7.3.3.3.4 Thermal/Infrared Imaging Examination Method

The thermal/infrared imaging examination method (i.e. thermography) is another approach for assessing the potential for CUI on insulated vessels and piping. Thermography is a rapid, passive inspection technique that produces a heat picture of the surface of a component using a thermal imaging infrared (IR) camera. IR cameras are used to detect damp spots in the insulation due to a temperature difference between the dry and the wet insulation.

IR cameras can detect surface temperature variations on the component as small as 0.18 °F (0.10 °C), though there must be a temperature differential across the thickness of the component of at least 18 °F (10 °C). Temperature variations on the component are displayed as different colors. Depending on the temperature of the product contained, “hot” or “cold” spots on the thermograph show up because of the effect of moisture increasing local thermal

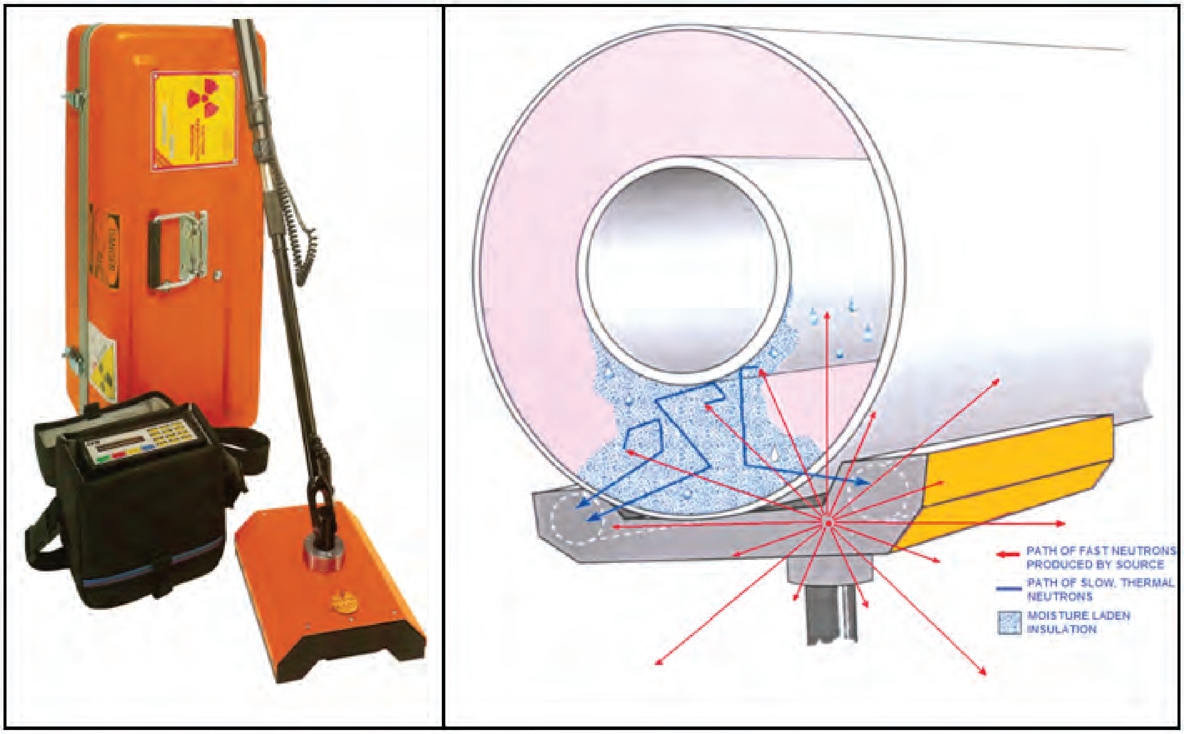


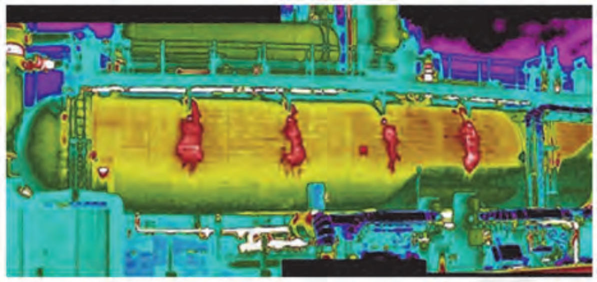
Figure 18—A Photo of a Neutron Backscatter System

conductivity in the component. Thermography is often carried out from as far away as 65 ft (20 m). Full inspection coverage can at times be difficult because of site obstructions such as existing piping or equipment during IR photo shooting. Figure 19 shows examples of IR thermographs.

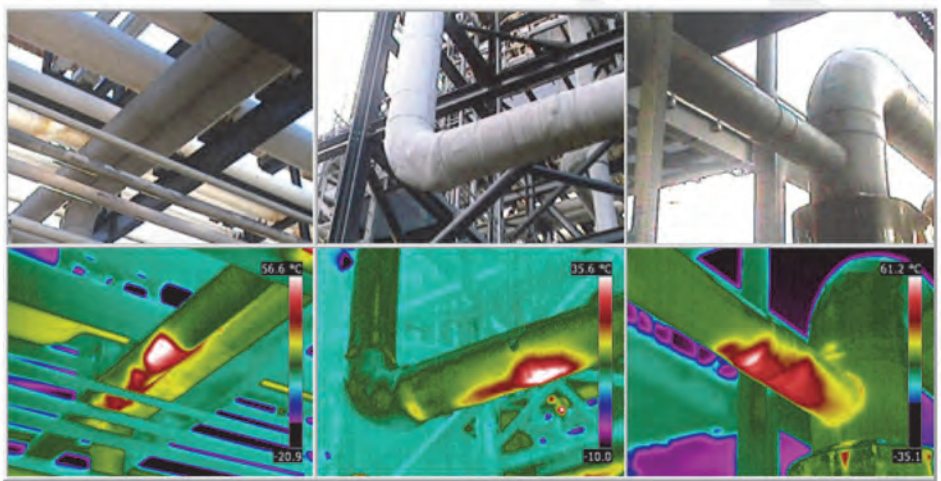
In some instances, IR surveys are conducted in conjunction with neutron backscatter examination. Conducting the IR survey two to three hours after the sun has set is advantageous since wet insulation holds the heat absorbed from solar rays longer than dry insulation. This can tend to promote more contrast in the thermograph. In general, thermographic inspection for CUI should be done in the absence of strong gusty winds (i.e. nonwindy conditions) since wet insulation maintains its heat longer. It should be noted that while water may be detected with this technique, it does not necessarily mean that CUI is occurring.

Advantages and disadvantages for thermal/infrared inspection are as follows.

- Advantages:
  - rapid method to detect damaged or wet insulation;
  - noninvasive, noncontact method that does not require direct access to the insulated surface (i.e. can be done from ground level without scaffolding);
  - easy-to-use method to highlight areas requiring inspection follow-up.
- Disadvantages:
  - does not detect corrosion but only areas where insulation may have been compromised (i.e. damaged or wet insulation);
  - not effective method if insulation has had sufficient time to dry out.



a) Desalter Vessel Showing Water Intrusion Under the Insulation



b) Saturated Insulation on Piping

Figure 19—Thermographs Showing Areas with Wet Insulation (in Red)

8 Risk-Based Inspection (RBI)

8.1 General

8.1.1 With regard to CUI/CUF, the purpose of RBI is to identify susceptible pressure vessels, piping, and fireproofed structural supports subject to CUI/CUF, to prioritize inspections, and to develop an inspection plan to manage risk. Specific guidance on the RBI process and procedures for CUI is provided in API 580, API 581, API 510, API 653, and API 570. A similar RBI process and procedure can be adopted for CUF assessment. An RBI assessment may be used to increase or decrease the inspection frequency and scope of CUI/CUF inspections when compared to time-based or condition-based inspection planning.

The information needed to assess the likelihood of failure due to CUI or CUF damage includes but is not limited to:

— specific site environment;

— material of construction;

— age of component;

— operating process temperature;

— exposure to intermittent/cyclic service;

— prior inspection histories/results;

— areas with missing insulation;

— type of insulation/fireproofing;

— age of insulation/fireproofing;

— type of coating present, if any;

— age of coating;

— presence and condition of steam tracing.

These data can be obtained from a variety of sources and can include the original engineering records, MOC databases, maintenance work order records, and inspection records. Other data that pertain to the physical condition of the component can be obtained from a field inspection. These inspections can be incorporated into the planned API 510, API 570, and API 653 external inspection programs or may be part of a special emphasis CUI inspection project.

8.1.2 Prior to conducting the assessment, the atmospheric environment of the area being assessed within the plant needs to be classified. Examples of atmospheric environment descriptors included in API 581 are arid/dry area, temperate area, severe area, arid marine/cooling tower drift area.

8.1.3 Though some users assess likelihood of failure for CUI and CUF using a quantitative assessment approach described in API 581, many users choose to perform a qualitative assessment approach to assess the likelihood of failure. Annex A shows an example of a points-based qualitative system for likelihood assessment that an owner/user could choose to utilize.

When conducting a qualitative assessment, the owner/user may choose to modify (i.e. add or eliminate) the number of parameters, change the description of individual parameter categories, modify the value of individual parameter ratings, or increase or decrease the minimum or maximum range of individual parameters or the total number of likelihood rating categories to address company or site-specific factors.

8.1.4 The owner/user should consider the differences between potential failure modes for each of the damage mechanisms when assessing consequence, namely

— corrosion hole from CUI (most frequently a small leak),

— cracking for ECSCC of austenitic/duplex stainless steels (most frequently a small leak),

— rupture/structural instability (rarer event).

While many CUI leaks occur from smaller pits, some CUI loss of integrity events have occurred as a result of larger locally thinned areas. The owner/user should assess the consequence of both types of risks in the risk assessment process.

8.1.5 Consequence assessment should conform to the documented site consequence assessment process. Guidance on RBI consequence assessment can be found in API 580 and API 581. Though CUI damage is most often likely to produce an equipment reliability issue, in some cases, safety and environmental issues can arise.

9 Design Practices to Minimize CUI

9.1 General

The design of hot and cold service insulation systems has to address certain specific requirements. Three of these requirements are common to both services and relate to coating of the substrate metal, selection of the insulation material and weatherproofing. A further requirement is the necessity for a vapor barrier in cold service. Each of these requirements is discussed in some detail below.

9.2 Coatings for Hot and Cold Services

9.2.1 The coating system provides protection from corrosion when water penetrates the insulation system. The coating system needs to be capable of operation under intermittent immersion service. Intermittent service is defined in many specifications from major petroleum and petrochemical companies as 15 % of time spent in the temperature range of risk. Equipment that operates or stands at ambient temperature for more than 15 % of its expected life should also be coated.

9.2.2 Carbon steel should be coated with one of the following coating types: epoxy amine, epoxy polyamide, or zinc phosphate phenolic, all of which may be used up to the maximum temperature limits recommended by the manufacturer of the particular product. It should be emphasized that the coating manufacturer's application instructions be strictly followed to optimize coating performance. This includes such conditions as relative humidity/temperature limitations, standards of surface preparation, and the length of time between priming and topcoating to prevent intercoat adhesion difficulties. Within the past several years, numerous owner/users have specified the application of TSA to reduce the potential for corrosion in applications prone to CUI damage. As with any applied coating, surface preparation and application concerns need to be addressed to maximize the service life of the coating (see 11.5).

9.2.3 If special protection is required, the surface should be degreased and then coated. Water glass (sodium silicate) is used to coat the surface when inhibited calcium silicate is the specified insulation material. A silicone-acrylic coating (guaranteed free from low melting point metals, e.g. zinc) is used when foam glass, mineral wool, etc., are the specified insulations. For stainless steel equipment, some operators specify wrapping the equipment with aluminum foil prior to insulating for additional protection by acting as both a physical and a galvanic barrier to preventing ECSCC.

9.3 Insulation Materials

9.3.1 General

As stated previously for both hot and cold service the nonwicking, nonabsorbent type of insulation is the first choice within the material's limits. Mineral wool, fiberglass, and calcium silicate have the highest tendency to absorb water and chlorides and therefore a higher susceptibility to CUI damage. Materials with a closed-cell structure like expanded perlite and cellular glass tend have a higher resistance to absorbing water. Contact-free insulation systems prevent accumulation of water and chloride buildup on the steel surface, thereby reducing the probability of CUI damage.

Common insulation systems for hot and cold services are outlined below. The lists shown below are not meant to indicate that these are the only materials that can be used in the services and temperature ranges. Owner /users may wish to review the advantages and disadvantages of insulation materials listed in Section 6 prior to selecting an insulation material for various applications. Alternately, owner/users may prefer to consult a subject matter expert to develop guidelines on the applicable insulation materials for specific service.

9.3.2 Ferritic Steel in Hot Service

Examples of insulation materials used on ferritic piping or equipment in hot service are shown below:

— Up to 200 °F (93 °C)—Cellular glass, expanded perlite, silica aerogel, mineral wool, fiberglass, or polyurethane foam.

— Over 200 °F (93 °C)—Cellular glass, expanded perlite, silica aerogel, mineral wool, or fiberglass up to their limits.

— Over 250 °F (120 °C)—Cellular glass, silica aerogel, mineral wool, fiberglass, or calcium silicate blocks up to their limits.

9.3.3 Ferritic Steel in Cold Service

Examples of insulation materials used on ferritic piping or equipment in cold service are shown below:

— –76 °F (–60 °C) to 800 °F (430 °C)—Cellular glass.

— –76 °F (–60 °C) to 200 °F (93 °C)—Polyurethane foam.

9.3.4 Austenitic/Duplex Stainless Steel in Hot Service

Examples of insulation materials used on austenitic or duplex stainless steel piping or equipment in hot service are shown below:

— Up to 400 °F (204 °C)—Cellular glass, expanded perlite, mineral wool, fiberglass.

— Over 400 °F (204 °C)—Mineral wool, expanded perlite, fiberglass, or inhibited calcium silicate.

9.3.5 Austenitic/Duplex Stainless Steel in Cold Service

Examples of insulation materials used on austenitic or duplex stainless steel piping or equipment in cold service are shown below:

— –436 °F (–260 °C) to 800 °F (430 °C)—Cellular glass.

— –260 °F (–196 °C) to 200 °F (93 °C)—Polyurethane foam.

9.3.6 Vapor Barrier

A vapor barrier is required for cold service applications. This barrier should be continuous and is usually provided by a glass fiber reinforced mesh impregnated with three coats of an elastomeric material. This elastomeric material should be compatible with the insulation material and flexible at the lowest expected ambient temperature. If it is to be left uncovered (i.e. unprotected by metallic weather proofing), the vapor barrier should be resistant to solar radiation.

9.4 Jacketing

9.4.1 General

Jacketing or weatherproofing is the final element of the system. In the form of a metallic covering, it should be considered mandatory for hot service but need only be used for cold service where the vapor barrier can be abused (mechanically damaged). Metallic jackets are manufactured from solid aluminum, zinc- or aluminum-coated sheet steel, or from stainless steel sheet metal. Jackets should be designed so that all joints are in the watershed position. Adequate overlaps should be employed coupled with the use of elastomeric sealants to prevent ingress of water either by gravity, by capillary action, or by wind drift.

9.4.2 Nozzles and Attachments

The areas of concern on an insulated, vertical vessel are illustrated in Figure 20. As indicated, the top head especially where nozzles, lifting lugs, etc. project through the insulation can be at greatest risk from CUI. Similarly the vertical walls are at risk at positions where horizontal attachments (support brackets, stiffener and/insulation rings, nozzles) pierce the insulation. Such attachments can provide paths for water to short circuit the weatherproofing/ insulation and contact the walls.

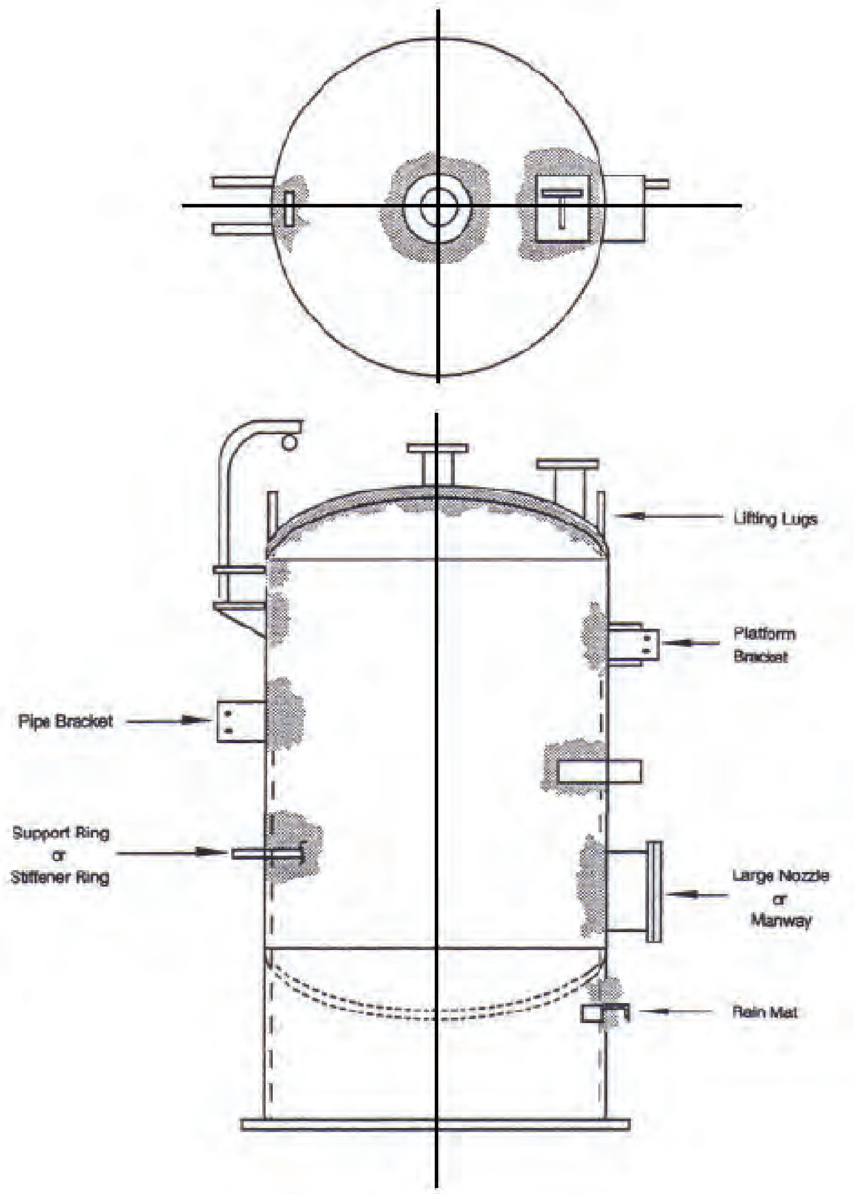


Figure 20—Areas of Concern for CUI in a Vertical Vessel

9.4.3 Appurtenances

Vessels, exchangers, tanks, and piping include a number of appurtenances that are required for support, reinforcement, and connection to other items. Details such as gussets, brackets, reinforcing pads, saddles, support shoes, vacuum rings, etc. fall into this category. These appurtenances make weatherproofing difficult as they provide preferential channels for the entry of water into the insulation. Needlessly complicated support details are difficult to insulate correctly, and insulation workers often seal these areas poorly unless closely supervised during insulation installation.

9.4.4 Insulation Laps and Folds

Jacketing should be installed in such a way as to eliminate water ingress. This includes sealing any breaks or penetrations in the sheeting using a silicone caulking material and locating the jacketing folds and overlaps in such a way that moisture cannot be trapped by the jacketing. Namely, folds in the jacketing on horizontal piping need to be located between the 4 o'clock and 8 o'clock position. On vertical piping, folds in the jacketing need to be located on the side away from the prevailing winds. Of course, jacketing joints need to be installed so that water tends to run off, rather than underneath, the joint.

9.4.5 Corrosion of Jacketing

Sometimes metal jackets suffer from underside corrosion in hot service. This is due to water trapped in the insulation during the insulation operations becoming vaporized. The vapor is driven to the jacket where it condenses to form alkaline or acidic solutions, depending on the insulation type. The cycle repeats and the corrosivity of the condensate increases and results in the corrosion of the aluminum or steel jacket. Metal jackets should contain moisture barriers on the inside. Where corrosion of the jacket has traditionally been a problem, plastic or all-weather types may provide a solution.

9.4.6 Techniques to Minimize Water Ingress

9.4.6.1 General

Examples of insulation techniques that can be adopted to minimize the possibility of water ingress at such attachments are shown for vessels and piping components in Annex B. In essence, all the techniques are based on preventing water breaching the external weatherproof covering. This primary objective is then further reinforced by the provision of secondary measures. These measures, which include the use of vapor barriers or multilayer insulation with staggered joints, are important if the external weatherproof is breached. If corrosion is to be prevented, attention should be given to the design and the installation of the insulation system and to the provision of suitable barriers to water ingress. These barriers should eliminate crevices that permit the concentration of moisture and chlorides. To this end, welded external attachments should be minimized. If these are unavoidable, welds should be continuous and the entire equipment should be protected with suitable barrier coatings. The primary safeguard against CUI is a continuous weatherproof barrier. Special attention should be paid to the application of insulation, in particular to the weatherproofing, around projections such as nozzles and clips because these offer ready paths for water to enter and migrate to the surfaces of the underlying metal.

9.4.6.2 Drain Holes in Jacketing

Small [e.g. $^{1}/_{4}$ in. (6 mm)] diameter drain holes can be drilled in rigid insulation on insulated hot piping to allow any water accumulating in the insulation to escape. Drain holes should be located at the bottom of vertical piping runs and along the bottom of horizontal piping. Water detectors can be installed at those positions to indicate the presence (drainage) of water and the opportunity to analyze the collected water for corrosion product content (i.e. indication of coating breakdown).

9.5 General Design Aspects

9.5.1 General

One of the prime objectives of the general design of equipment and piping that is insulated should be to minimize CUI.

9.5.2 Design Simplification

As a general rule of thumb, complicated designs are difficult to insulate and should be avoided. Figure 21 is an example of a design layout that is difficult to insulate and weatherproof and therefore had from the outset a high potential for CUI.

Figure 21—Example of a Design/Layout That is Difficult to Insulate

9.5.3 Pressure Vessels

For the purposes of this document, “pressure vessels” include all major types of static equipment (e.g. columns, heat exchangers, etc.). Design considerations for pressure vessels include the following.

a) The design and orientation of any protrusions should be configured to aid effective water shedding.

b) If possible, seal-welded sealing discs should be installed on vessel nozzles and other protrusions through the insulation. Seal-welded plates are useful in diverting water away from critical locations. These can be used, for example, on nozzles for vessel shells and tank roofs to divert water away from the protrusion through the jacketing. However, this requires attention to design detail, particularly for horizontal protrusions. An example of sealing discs on vessel nozzles is given in Figure A.6.

c) To aid insulation fit-up and the achievement of a water tight seal, attachments supporting ancillary items such as ladders, gantries, etc. on insulated vessels should be of a sufficient length such that they protrude beyond the insulation thickness by at least 100 mm (4 in.) when measured perpendicular to the surface of the insulation.

d) Nozzles and manways should be at least 76 mm (3 in.) longer than the insulation thickness to allow for the insulation and jacketing to be terminated and sealed independently of the nozzle flange insulation and to give proper clearance for flange bolt withdrawal without damaging the nozzle insulation.

e) Bucket-type insulation support rings (as described in NACE SP0198), which could act as a moisture trap, should be avoided.

f) If installed bucket-type insulation support rings should be drilled to allow water to escape (note that maintaining rust-free drain holes is a long-term maintenance issue).

g) If practicable, insulation support rings should be attached to brackets that are seal welded to the vessel shell in such a way that there is a gap between the support and the shell. An example of such a support is given in Figure A.7.

h) Nameplates.

   1) Nameplates on insulated vessels should be fully incorporated in the insulation.

   2) Duplicate nameplates should be prepared and attached to the pressure vessel. Duplicate nameplates should exactly reproduce the layout and information content of the original. The location and method of attachment of the duplicate to the outside of the insulation may vary depending on the vessel layout.

9.5.4 Piping

9.5.4.1 General

Design considerations for piping include the following.

a) Supports for insulated piping should, if possible, make use of load-bearing insulation/jacketing to allow the pipe to be supported without the need to penetrate the insulation. If load-bearing insulation/jacketing cannot be used, the minimum length of the support should be four times the insulation thickness. Pipe supports are difficult to seal, and the above modification enables the insulation jacketing to be continuous beneath the support clamp.

b) Water hoods should be fitted to vertical overhead pipe supports to direct water away from potential entry points where the support penetrates the insulation.

c) Separation distances for insulated piping should be 1.5 times the sum of the insulation thicknesses to be applied to the pipes. For example, the minimum pipe to pipe separation of two lines the first with 4 in. (100 mm) of insulation and the second with 1.2 in. (30 mm) should be (4 in. + 1.2 in.) × 1.5 = 7.8 in. or (100 mm + 30 mm) × 1.5 = 195 mm.

d) Separation distance between insulated piping and from structural steelwork should be two times the insulation thickness.

e) If possible, dead-legs in insulated piping should be avoided. Piping dead-legs can be particularly prone to CUI. Heat leaking into dead-legs in cold piping or heat loss leading to cooling of dead-legs in hot piping can bring the effective operating temperature at the dead-leg into a range in which the risk of CUI is much higher. Considerations should be given to whether or not insulating dead-legs could cause internal corrosion such as dew point corrosion.

f) Heat tracing.

   1) If insulated piping is steam traced, joints in steam-tracing pipework should be located outside the insulation jacketing. Steam-tracing pipework should enter and leave the insulation at the lowest possible point. Steam leaks often occur at joints in the tracing pipework. If the joints are inside the insulation, leaking steam can rapidly saturate the insulation and promote very rapid corrosion.

   2) Electric heat tracing should be permanently fixed to the pipe independent of the insulation material.

   3) Penetrations of electric heat tracing tape through the jacketing should be fitted with appropriate cable grommets or glands to prevent moisture ingress. The penetrations should be positioned away from the prevailing weather and between the 4 o'clock and 8 o'clock positions on horizontal pipe.

9.5.4.2 Valves and Instruments

Design considerations for valves and instruments include the following.

a) Valves and instruments such as pressure and temperature gauges in insulated piping should have stems of length equal to at least twice the thickness of the insulation.

b) If insulation will be frequently removed for maintenance or inspection (e.g. at relief valves), the insulation on the pipework should be terminated and capped at a location that allows flange breaking without interference with the sealed cap. Insulation and jacketing of isolation and relief valves should be independent of pipe insulation.

9.5.5 Tankage

Design considerations for tankage include the following.

a) *Roof Overhang on Fixed Roof Tanks*—On a tank that is to be insulated the tank roof should overhang the shell by at least the shell insulation thickness plus 2 in. (50 mm). This is to ensure that water running off the tank roof is led away from the insulation. If the tank roof is also insulated, it helps prevent any moisture that has gotten into the roof insulation from passing down into the insulation on the shell.

b) *Ancillary Attachments to Tank Shells and Roofs*—

   1) ancillary attachments such as ladders, stairways, level controls, etc. should have a standoff of at least four times the insulation thickness;

   2) for roof-entry pipework supports, the pipe standoff should be a minimum of 6 in. (150 mm) greater than the combined thickness of the insulation on the tank shell and the insulation thickness on the pipe.

c) *Double Shell Insulated Tanks*—Double shell insulated tanks should be designed in such a way as to prevent moisture getting into the void space. Double shell insulated tanks have the insulation installed in the void space between the two shells.

9.5.6 Small Bore Pipe and Fittings

Small bore pipe and fittings can be particularly vulnerable to CUI because the wall thicknesses required for pressure containment are small. Increasing the thickness of carbon steel small bore piping to provide a corrosion allowance can add a safety factor, but it does not prevent CUI and does not remove the need to inspect for CUI. Some sites use stainless steel for thin wall small bore piping and fittings.

9.5.7 Other Concerns

9.5.7.1 Shelters from Prevailing Weather

If there is a high concentration of insulated pipework and equipment in a small area in a location where precipitation is likely to be frequent, a permanent shelter should be considered to be erected around the plant to protect the insulated area from the weather. If rainfall is a regular feature of the local climate then insulated equipment enclosed in weatherproof shelters is less likely to suffer from CUI.

9.5.7.2 Walkways

Steps and/or bridges as appropriate should be provided to allow personnel to cross low-level pipe tracks without stepping on insulation. Damage to insulation caused by foot traffic on insulated piping can be an entry point for moisture and has been a major contributor to increasing the likelihood of CUI.

9.6 Insulation

Design considerations for insulation include the following.

a) Insulation materials should be installed in such a manner that the external surface should be as uniform as possible and that the jacketing is applied and sealed properly.

b) Consider the use of standoffs between the insulation and the piping or vessel surface when fibrous insulation materials are used in areas with a potential for CUI in order to keep wet insulation from direct contact with the insulated surface.

c) Some insulation materials have coefficients of linear expansion that are significantly different than steel. The insulation system design should consider the installation of expansion and contraction joints to accommodate the difference in expansion coefficients.

d) Parts of the insulation system intended to be removed and replaced during unit operations, such as valve boxes, need to be designed to undergo multiple removal/replacement cycles.

9.7 Heat-traced Systems

Steam-tracing systems are manufactured using carbon steel, copper, stainless steel, or nickel-based (i.e. Incoloy) tubing materials. Though nickel-based tubing materials are expensive, they have a lower probability of in-service failure and may be justified on high-criticality systems. At many sites, nickel-based tubing materials such as Incoloy 825 are considered as standard for instrument systems where they are economic or risk appropriate.

When extensive insulation removal is planned for a steam-traced system, consideration should be given to renewing the associated tracing with tubing couplings/joints outside of the insulation, or replacement with an electric-traced system.

9.8 Protective Coatings and Caulk

9.8.1 General

The primary element in preventing CUI damage is to keep moisture from reaching the surface of the insulated component. This can be achieved by either

1) the application of coatings to the surface of the component, or

2) preventing moisture from penetrating the insulation system.

A well-designed coating system applied to the surface of a component prior to insulation, together with a properly insulated system, can provide greater resistance to CUI damage and reduced maintenance costs. In addition to the benefits associated with the application of a protective surface coating system, the application and maintenance of insulation jacket caulking is a critical component of preventing moisture from breaching the insulation system.

9.8.2 Coating Considerations

A coating system should protect against water or corrosives for long periods. Highly permeable organic coatings allow corrosion to start behind the coating even in the absence of breaks or pinholes. As a result, organic coating systems that are suitable for immersion service are usually preferred where there is a potential for CUI damage. Typically, a prime coat and topcoat are required to adequately protect a component from corrosion. Application of solely a primer will not provide adequate corrosion resistance.

Before a coating is applied to a component surfaces, the surface should be dry and clean from contaminants and rust. For CUI applications, a white-metal blast cleaning (SSPC SP-5 or equivalent) is preferred, though a “good” near-white-metal blast cleaning (SSPC-10 or equivalent) may be acceptable. The adequacy of the surface preparation can significantly impact the durability of the coating. For CUI applications, high-build epoxies or epoxy-phenolics are often specified at temperatures up to about 250 °F (120 °C). At higher temperatures, a high-temperature coating (e.g. a two-coat heat-resisting silicone coating) is required.

It should be noted that many coating systems fail after 10 years in service. After the coating breaks down, the bare steel can be attacked by CUI. By contrast, TSA coatings are generally reported to have a useful service lifetime in excess of 35 years though service life can be reduced because of improper coating application (see 11.5.4).

9.8.3 Caulking Considerations

Caulking should be done immediately after the insulation jacket is installed since moisture could enter through the open seams if left unsealed for a period of time. Protrusions or penetrations through the insulation, such as nozzles, support lugs, and so forth, should be sealed with a bead of good caulking compound. In order to achieve a satisfactory caulked joint, the separation between jacketing should not be greater than 3.2 mm ($^1/_8$ in.). A minimum of 6 mm ($^1/_4$ in.) of caulk should be applied to jacket joints. Caulking should not be featheredged since the life of the seal depends on a uniform material thickness. Feathered edges curl and pull away from the jacketing.

Only silicone rubber caulking remains resilient for many years and is resistant to higher temperatures and many chemicals. Pigmented (i.e. colored) silicone rubber caulking provides a higher temperature and UV resistance compared to translucent-type caulk. With time, caulking materials dry out and lose flexibility. Areas around nozzles, manways, and on vessel heads should be inspected periodically to maintain the integrity of the insulation system.

9.9 Shutdown/Mothballing

There is a high potential for CUI damage of insulated carbon and low alloy steel on equipment that will be shutdown or mothballed for an extended period. It is prudent to remove all insulation and fireproofing when equipment or piping systems are mothballed. Generally, corrosion rates of carbon and low alloy steels under insulation are significantly higher than atmospheric corrosion.

9.10 Quality Control/Quality Assurance

The insulation materials used for each application need to comply with all applicable national or international regulations. The site should obtain certificates of conformance for the insulation materials used. They should be sufficiently detailed to show the applicable regulations.

The site should also establish a quality control system covering the materials being used. The quality control system should cover all steps from insulation procurement through the installation process. The quality control system should list the responsibilities of personnel inspecting the insulation materials and the responsibilities of personnel supervising the installation work. It should also list all hold and witness points.

10 Design Practices to Minimize CUF

10.1 General

10.1.1 Fireproofing is employed to minimize the escalation of a fire that would occur with the failure of structural supports and the overheating of pressure vessels. The failure point for steel is generally considered to be 1000 °F (537 °C). At this temperature, the yield strength of structural steel is roughly 50 % of its room temperature strength.

The goal of fireproofing is to prevent structural steel from reaching 1000 °F (537 °C) for some period of time to allow more time for plant personnel to:

a) evacuate,

b) fight the fire,

c) shut off the fuel supply for the fire, and

d) shut down the process to minimize the overall damage incurred.

10.1.2 The traditional method of fireproofing has been pour-in-place concrete or gunite. Other fireproofing materials, such as lightweight cements, prefabricated cementitious board, and intumescent coatings are used. Lightweight coatings are used primarily in areas where weight reduction is a significant benefit.

10.1.3 The decision to fireproof is driven by risk-based analysis. One needs to first consider the nature of the fire threat and then make an assessment of the required period of fire endurance for a wide variety of equipment including structural steel, pressure vessels, heat exchangers, pipe supports, liquefied petroleum gas spheres, and bullets, valves, and cable trays. The location of specific equipment within a process unit is important, as is a unit's location with regard to neighboring facilities. Guidance on the selection, application, and maintenance of fireproofing systems is provided in API 2218.

10.2 Dense and Lightweight Concrete

Structural steelwork and vessel skirts with concrete or vermiculite cement fireproofing should be coated with protective primers and topcoat sealers prior to fireproofing because of the effect of chlorides on the steel surface in moist environments. Weather shields should be installed, where feasible, at the top edge of the sealed, fireproofed joint to prevent water getting between the structural steel and the fireproofing. The use of nonpotable water and poor mixing can lead to reduced durability of concrete and cementitious fireproofing. Using water that contains high levels of chloride can lead to accelerated corrosion. Again, the buildup of corrosion products between the structural steel and the fireproofing can cause cracking and spalling of the fireproofing.

10.3 Lightweight Cementitious Products

As in the preceding section, the base metal substrate also needs to be coated with protective primers and topcoat sealers prior to fireproofing to diminish the risk for CUF. These materials are usually limited to areas that are not prone to mechanical damage and are typically used in areas above a 10-ft (3-m) elevation. Mechanical damage of these materials has been known to occur, thereby increasing the potential for CUF on the structure and reducing their overall effectiveness as fireproofing.

10.4 Intumescent Coatings and Subliming Compounds

Coatings that provide fireproofing by intumescing or subliming develop good adhesion to properly coated steel. As a result, the risk of CUF with these coatings is much reduced. It is important, however, that coating work conducted prior to the application of the fireproofing is done to a high standard. It is important that the coatings are allowed to properly cure before the fireproofing is applied. Additionally, the fireproofing may require overcoating to protect it from long-term exposure to UV light. This exposure can be damaging to the fireproofing material. The fireproofing manufacturer should be consulted for their recommendations on overcoating.

10.5 Protective Coatings

There is always a chance that water may get behind fireproofing. In such a case, the coating is all that is preventing corrosion from occurring. It is therefore important that the proper coating be selected for the exposure conditions and that the surface be prepared and the coating be applied in accordance with the manufacturer's recommendation.

10.6 Quality Control/Quality Assurance

Fireproofing materials have evolved from traditional materials (i.e. dense and lightweight concrete) to higher technology materials (i.e. intumescent rigid/flexible epoxies, flexible endothermic wraps, etc.). Satisfactory performance of fireproofing depends on knowledge of materials and application techniques. Inspection by qualified personnel is also crucial in assuring that the fireproofing performs satisfactorily over the expected life of the fireproofing. It is essential that site and contract personnel are familiar with the site specification and fireproofing manufacturer's requirements. API 2218 provides guidance on quality control of fireproofing.

11 Maintenance and Mitigation of CUI/CUF Issues

11.1 General

Properly designed and installed insulation systems should normally require little maintenance. However, failing insulation systems are very often detected only when in poor shape and require significant repair. Routine maintenance practice should be extended by periodic scheduled inspections, preventive maintenance, and can include a long-term strategy based on RBI principles.

Shortcomings can then be detected at the earliest stage, preventing uncontrolled deterioration of the insulation system with consequential risk of CUI. In particular, inspection surveys should be carried out after shutdowns because during shutdowns insulation systems are sometimes removed and not properly reinstalled or the systems are damaged (e.g. because of falling scaffolding poles).

After an inspection survey has been completed, the reported damage and remarks should be translated into a plan of action for remedial and preventive maintenance. The recommendations for preventive maintenance needs to be prioritized for follow-up actions to prevent future or repeated damage to insulation or the underlying surfaces. Issues that should be considered are as follows.

a) Preventing water ingress due to inadequacy of design by:

   1) repositioning of supports and brackets;

   2) avoiding spraying firewater during fire drills on insulated tanks or equipment; and

   3) installing rainwater shields; and

   4) damaged or saturated insulation should be discarded and the insulated metal surfaces cleaned, derusted, and coated before installing the new insulating material.

b) Preventing insulation/jacketing damage due to operations or maintenance activities by:

   1) installing a walkway and/or platform over insulated pipes in a pipe track or at piping manifolds;

   2) rerouting of pedestrians by putting up hand railings;

   3) providing instructions to contractor/scaffolding personnel regarding appropriate protection of site insulation systems.

c) Removing unneeded insulation.

11.2 Programmed/Condition-based Maintenance

Based on the results of inspection surveys, the scope of long-term insulation maintenance can be determined and priorities can be set in accordance with the reliability-centered maintenance principles.

In order to systematically control the upgrading of existing insulation in a plant, the various units should be divided into manageable areas indicated on a plot plan and the work carried out by area. Simultaneously, maintenance painting in the same area should be scheduled.

Progress of work can then be properly recorded, and costs for scaffolding should decrease substantially as compared to when piping systems are followed or when work is carried out randomly throughout the plant. It should be noted that risk mitigation needs to be balanced with effective cost management. Site personnel should determine the effectiveness of block rejuvenation recognizing that some higher risk equipment/piping will not be mitigated until the block maintenance crew arrives at a later date.

11.3 Execution

When executing maintenance work, care should be taken to remove existing insulation materials in order to allow their reuse. Slabs, pipe sections, or preformed covers for valves, fittings, etc. should be removed carefully and properly stored.

Temporary protection should be provided to adjacent insulation to prevent damage or water ingress during mechanical maintenance work.

After repair of damaged hot insulation, the jacketing of the replaced area and its direct vicinity should be checked to establish proper repair of the weather protection of the complete system. For cold insulation, the vapor barrier of the replaced area should be applied with sufficient overlap on the existing undamaged vapor barrier.

11.4 Deluge System Issues

All of the normal inspection issues associated with CUI will also apply in areas under deluge systems. Periodic inspection using either neutron back backscatter or IR thermography should be considered because of the high potential for finding wet insulation in these systems. Periodic maintenance of the weather shield is an important step in preventing CUI damage of equipment under deluge systems and should include:

1) repair of damage to the weather shield,

2) inspection and removal of drain hole blockages,

3) resealing of any damaged weather shield seams,

4) repair of damaged coatings when detected,

5) routine external visual inspections of the integrity of the insulation system.

11.5 Mitigation of CUI Damage

11.5.1 General

There are several approaches that are used to mitigate CUI damage. These include approaches to protecting the surface of the metallic piping (i.e. organic coatings, TSA, and aluminum foil for stainless steel), the installation of protective cages in locations where piping is insulated solely for personnel protection, and performing periodic maintenance on the insulation system.

11.5.2 Organic Coatings

The application of organic coatings on carbon steel equipment beneath insulation is an effective method of having a physical barrier to the corrosive electrolytes Organic coatings are effective only if the surface has been prepared properly and a holiday-free coated surface is obtained. In general, the average life of an organic coating system is 5 to 13 years. In some cases, when a correctly selected and applied coating system is used, a 20-year service life can be achieved. Some of the parameters that need to be considered when selecting a coating system include:

— surface-preparation requirements,

— environmental requirements,

— compatibility with insulating material,

— coating tests,

— coating vendor selection,

— specifications,

— inspection,

— selection of a coating applicator.

Coating systems that have been used successfully in the process industries include liquid-applied coatings like epoxies, urethanes, and polyurethanes; fusion-bonded coatings; brushable coal tar or asphalt-based coatings; mineralization coatings; and tapes. More information on the selection of protective coatings is available from coating manufacturers' literature and in NACE SP0198.

11.5.3 Aluminum Foil to Protect Austenitic/Duplex Stainless Steel

Experience has shown that organic coatings do not necessarily provide an effective barrier to ECSCC. When properly installed, aluminum foil wrapping of piping is a effective method to protect austenitic and duplex stainless steel from ECSCC. The primary benefit of aluminum foil wrapping is by acting as a sacrificial anode to provide electrochemical (i.e. cathodic) protection against ECSCC. The wrapped aluminium foil may also act as a barrier, but its ability to serve as a barrier is highly dependent on its application.

Prior to wrapping, the surface should be washed with demineralized water to remove chloride from the uncoated piping. Solvent cleaning (i.e. SSPC SP-1) is not necessary unless oil or grease is present on the surface. Aluminum foil wrapping of the piping takes less time to install than applying a coating to the surface of the pipe. As shown in Figure 22, vertical sections of piping should be wrapped from the lowest point of the run to the highest point of the run to prevent water from getting under the aluminum foil. Aluminum or stainless wire should be used to hold the foil in place. Foil should be molded around flanges and fittings. Steam-traced lines should be double wrapped, with the first layer applied directly to the pipe, followed by the steam tracing, and then the second layer of foil over the top of the steam tracing.

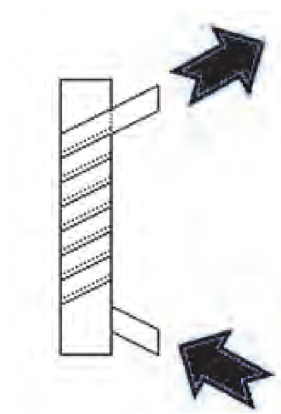


Figure 22—Vertical Piping Should Be Wrapped from Bottom-to-top with an Overlap

Although aluminium foil has been effective in preventing ECSCC under thermal insulation on austenitic and duplex stainless steel piping and vessels, its use may be limited to application on piping of 24 in. NPS or smaller based on economics. Above 24 in. NPS, piping and vessels use of TSA is generally more economic. Successful long-term use of aluminium foil relies on the maintenance of the weatherproofing system. While the aluminium foil does provide protection from ECSCC in immersion conditions its life is greatly reduced.

11.5.4 Thermal Spray Aluminium to Protect Steel

Thermally sprayed aluminum coatings are applied by either the electric arc spraying (also referred to as metallizing) or oxy-fuel wire spraying (also referred to as flame spraying) process (see Figure 23 and Figure 24).

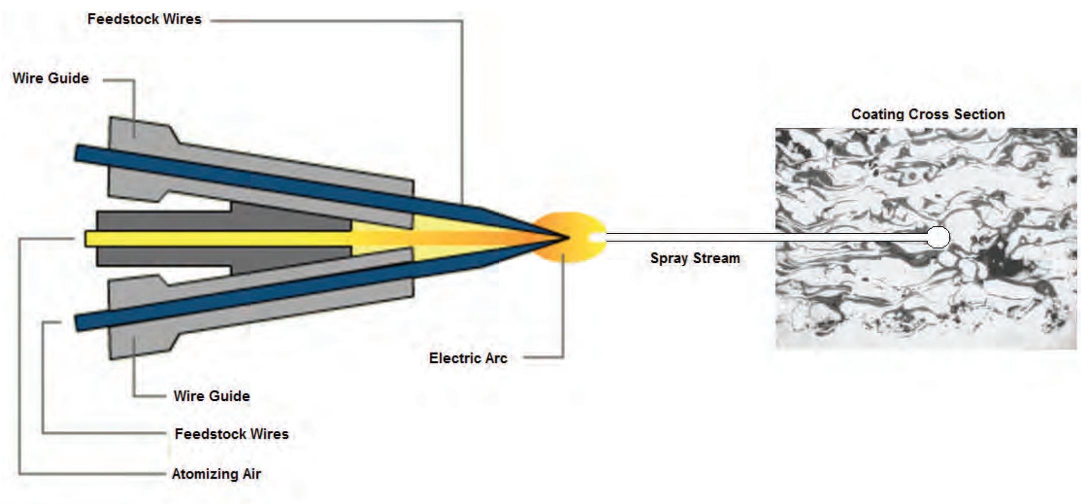


Figure 23—Schematic of Two-wire Electric Spray Processes and Deposit Microstructure

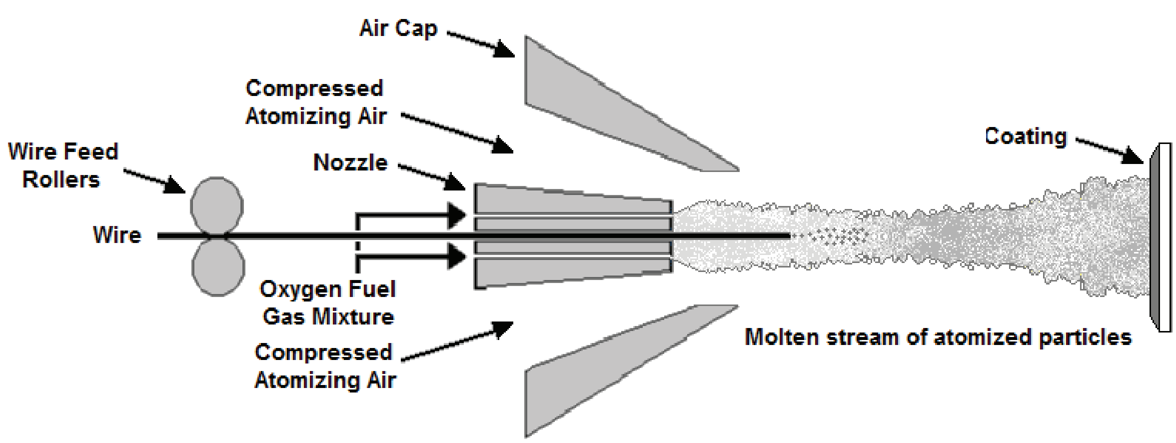


Figure 24—Schematic of Oxy-fuel Wire Spray Processes

In the electric spray process (Figure 23), the two aluminum wires are continuously fed toward each other to the gun tip at a uniform speed. A low-voltage direct current power supply is used, with one wire serving as the cathode and the other as the anode. As the wires leave the wire guides, they produce an electric arc at the point just before the wires meet. The high-temperature arc [>9000 °F (>5500 °C)] that is produced melts the wires. High-pressure compressed air, injected into the gun, produces a fine spray of aluminum droplets. As the spherical droplets impact the surface, they flatten to produce a platelet-like structure that is a mixture of coating, oxides, and porosity. A high magnification view of the deposit cross section is shown in Figure 23. The particles are mechanically bonded to the metal substrate.

In the oxy-fuel wire spray process (see Figure 24), drive rollers continuously feed the wire to the tip of the spray gun. A mixture of a combustion gas (i.e. either acetylene, propane, or methyl acetylene-propadiene) and oxygen are combined and ignited at the tip of the spray gun to melt the wire. The molten metal is then atomized by the surrounding jet of compressed air, creating a stream of aluminum droplets that are propelled to the metal substrate. The flame temperature of the combusted gas is significantly lower than the arc temperature of two-wire electric process [i.e. ~3100 °F (~1700 °C)]. Flame spray deposits are primarily mechanically bonded to the metal substrate and have lower bond strength than the two-wire electric spray process.

Since weather barriers and insulation are often not well maintained at regular intervals, a good, well-adhered surface coating is an important parameter in preventing CUI damage to the equipment and piping. Another key factor to a long service life for the coating is a well prepared surface. At a minimum, the surface needs to be prepared to a near-white-metal blast cleaned surface (SSPC SP-10 or equivalent).

Aluminum's affinity for oxygen and adherent and nonwater soluble oxide provides long-term CUI protection by serving as a barrier film and then providing catholic protection to the underlying carbon steel at breaks in the coating. TSA applications emit no volatile organic compounds and do not require "dry time" between coats. Two key elements to minimize the potential for CUI include having a surface that has been abrasively blasted to a near-white-metal condition (i.e. SSPC SP-10 or greater) and a coating thickness of 0.010 in. (0.25 mm). The minimum thickness of 10 mils, applied in one application by a crosshatched spray pattern, deposits a near pore free barrier surface with minimum size that will fill with aluminum oxide in service.

The importance of applied thickness in determining service life of the TSA is illustrated in Equation (1), developed by Thomason [11].

$$\mathrm{SL} = \frac{0.64 \times t_{\mathrm{TSA}}}{A_{\mathrm{s}}} \tag{1}$$

where

SL is the service life (years);

t_{TSA} is the thickness (μm);

A_{s} is the percent of area of bare steel.

TSA coatings are generally reported to have a useful service lifetime in excess of 35 years. Within the past few years there have been a few reports of TSA coatings failure in offshore applications after less than 10 years service. Factors that can influence the performance of TSA coatings include the following.

a) *Quality of Surface Preparation*—The steel surface should be prepared to an SSPC SP-10 or SIS Sa 2 1/2 surface finish.

b) *Quality of the Wire*—The wire should be free of kinks and should not contain visible oxide particles on the surface of the wire that could affect application, density, or adhesion of the coating.

c) *Environmental Conditions*—The relative humidity should be less than 85 %, and the steel surface temperature should be at least 5 °F (3 °C) above the dew point throughout the blasting and coating process.

d) *Coating Thickness*—The as-applied TSA thickness should not be less than 0.010 in. (250 μm) thick.

e) *Sealer Application*—When overcoated with an organic coating, the seal coat should not be greater than 0.002 in. (50 μm) thick.

f) *Applicator/Operator Experience*—When a applicator/operator has limited experience, the owner/user should consider increased QA/QC controls.

[11] Thomason, W. H., "Cathodic Protection of Submerged Steel with Thermally Sprayed Aluminum Coatings," Corrosion 84, Paper 338.

The service life approximation based on Equation (1) does not take into account the barrier effect of the TSA coating. It only takes into account that the failure mode of TSA is from anodic dissolution of the aluminum as it supplies cathodic protection to the carbon steel.

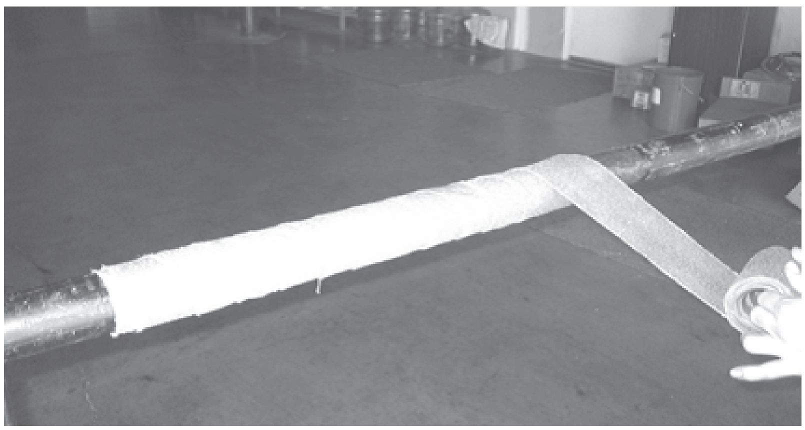
11.5.5 Tape Wraps

Petroleum-based tape wrapped systems have been developed to protect metal surfaces in severe environments for difficult to protect geometries [see Figure 25 a)]. These systems are typically composed of:

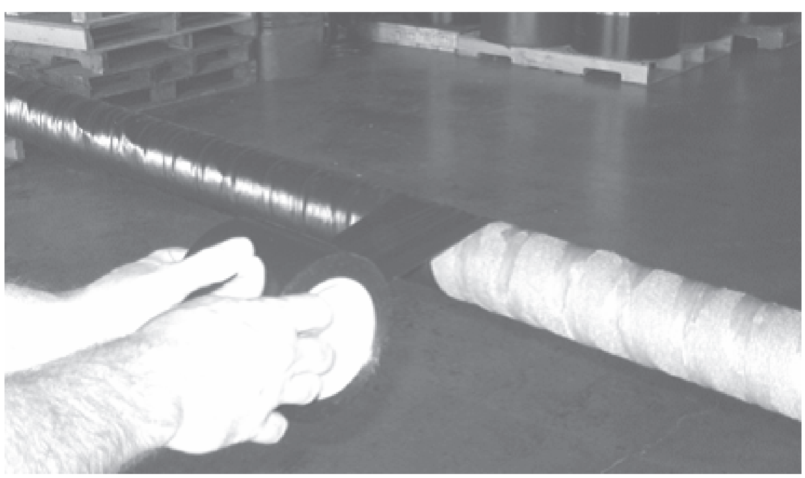
1) a surface priming paste to displace surface moisture, passivate surface oxides, and fill in small irregularities in the substrate;

2) a mastic filler to ease contours around irregular shapes such as pipe joints, flanges, valves, bolts, and other irregular shapes; and

3) a nonwoven bonded synthetic fabric, fully impregnated, and coated with natural petroleum.



a) Nonwoven Bonded Synthetic Fabric Impregnated with Natural Petroleum Being Applied to a Mastic Coated Surface



b) PVC Film Being Applied Over a Petroleum-based Tape Wrap

Figure 25—Example of a Petroleum-based Tape Wrap System

Prior to application of the priming paste, the surface should be solvent cleaned (per SSPC SP-1) to remove dirt, grease, and oil from the surface. In addition, weld spatter and sharp points/edges should also be removed. Hand or power tools (per SSPC SP-2/SSPC SP-3 or SSI St. 2/SSI St. 3) can be used to remove loose surface rust, paint, and foreign matter from the surface. High-pressure water blasting may be used to prepare the surface.

In some situations, a stabilized, plasticized, PVC film coated with an anticorrosive pressure sensitive adhesive can be used to wrap over petrolatum tapes to provide color coding and additional protection [see Figure 25 b)]. These systems wraps have been used in some offshore applications to replace metallic jacketed insulation because of their ability to provide an improved sealing capability.

11.5.6 Personnel Protective Cages

Equipment or piping operating above 140 °F (60 °C) poses a risk to personnel when skin comes in contact with the hot metal surface. In many instances, these surfaces are insulated for the sole purpose of personnel protection from the hot metal surface. The unnecessary use of thermal insulation creates a location for potential corrosion. In these cases, the insulation should be removed and wire "standoff" cages should be used instead. These cages are simple in design, low in cost, and eliminate CUI concerns and costs associated with maintenance of the insulation system. Examples of different types of personnel protective cages are shown in Figure 26.

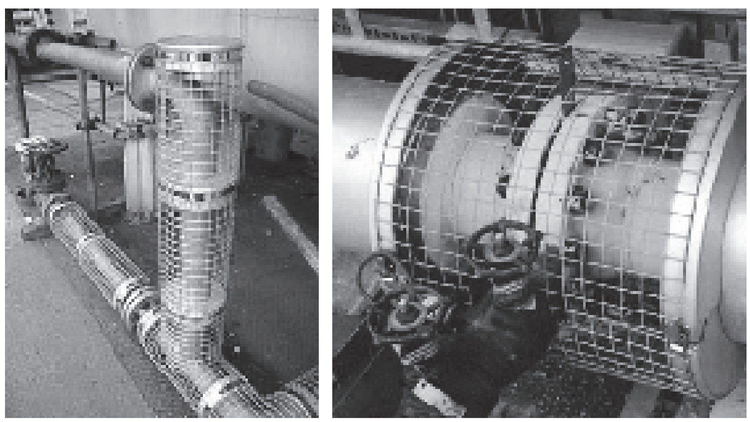


Figure 26—Photograph of a Personnel Protective Cage on a Vertical and Elbow Section of Piping (left) and a Removable Personnel Protective Cage on a Valve (right)

11.5.7 Insulation System Maintenance

11.5.7.1 General

Regardless of the type of jacketing and insulation, jacketing is used to ensure both the short-term and long-term performance of the insulation in the particular application. Assuming the insulation system has been properly designed and installed correctly, it will only perform as designed if properly maintained.

11.5.7.2 Jacketing

Breaches in the jacketing system, as shown in Figure 2, serve as potential access points for water ingress. The areas directly below these jacketing breaches are prone to CUI damage. Damage is likely to occur at the low point of the piping run where water can accumulate. The solution to this problem is to make sure the insulation is properly supported, replace damaged insulation, and reinstall the insulation jacketing.

11.5.7.3 Caulking

Figure 27 shows one of the piping segments (i.e. left arrow) with newly jacketed insulation system. The lap and butt joints of the jacketing are effectively sealed with caulk piping to prevent moisture ingress. However, when temperatures change, materials expand and contract causing cracks in the caulking, allowing moisture to penetrate the insulation system. Damage to the caulk seal may not be detected until the jacketing is removed. If undetected, CUI of the piping can occur. The only effective solution for this issue is to periodically dismantle a section, inspect the sealants, and determine whether the entire system needs to be resealed.

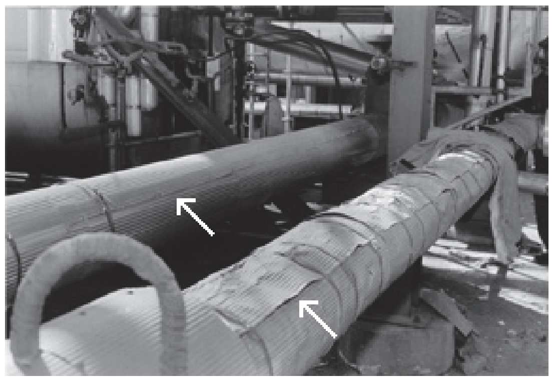


Figure 27—Photo Showing Piping with and Without Damage to the Insulation System

11.5.7.4 Insulation

Figure 27 also shows one of the piping segments (i.e. on right) with significant damage to the insulation system, both the insulation and jacketing, due to excessive foot traffic. Failure to replace this insulation system may result in excessively high heat loss and water intrusion. This has the potential to cause CUI damage to the piping. One solution to this problem would be to replace the entire insulation system and to modify site maintenance practices to avoid damage to insulated piping systems. An alternate approach would be to replace the insulation with high compressive strength material.

11.5.8 Installation Craftsmanship

11.5.8.1 General

Installation craftsmanship of jacketing/weather barriers can have a great effect on an insulation system's performance and life. It is a critical problem with those insulation systems that operate in the CUI temperature range, cycle in temperatures, or may be shut down for periods of time. A poorly installed insulation system ultimately lets moisture or corrosive chemicals into the insulation, and often to the insulated surface, allowing the start of CUI.

11.5.8.2 Caulking and Sealants

Caulking and sealants are barriers to moisture intrusion and may be installed improperly in a number of ways. They may not be installed (see Figure 28) or may be installed incorrectly either by missing sections or by wiping or smoothing the sealant bead once it has been installed.

Smoothing the sealant is often done to provide a more attractive finished appearance but may result in a large amount of the sealant material being removed. This can potentially reduce the life of the sealant and increase the chance of a leak.

Figure 28—Example of Jacketing Joint with Missing Caulking

11.5.8.3 Jacketing

Jacket materials installed with improper “fit and finish” provide easy path for water access (see Figure 29). Gaps between jacket components larger than 0.125 in. (3.2 mm) cannot be successfully sealed with caulking and sealants. Stresses and natural movement between these parts can cause the sealants to fail prematurely, letting in moisture and contaminating the insulation.

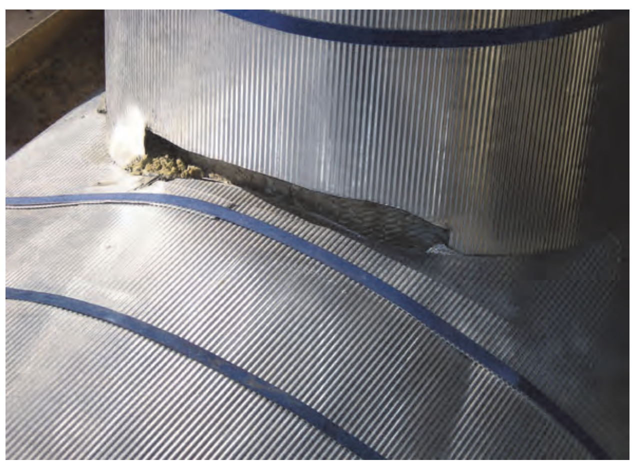


Figure 29—Example of Poor Jacketing Fit-up

Jacketing or weather barriers can also be installed improperly by not providing the proper ability to shed rain (see Figure 30). On vertical sections, this happens when lower sections of the jacketing material are installed over the top of the upper sections. On horizontal sections, it happens when the lap section is installed close to the top or bottom of piping rather than to the sides. It can also happen when a section of jacketing is wrapped around the insulation such that the upper section of the jacket horizontal lap is overlapped by the lower section. All of these installation errors allow water into the insulation system.

Insulation terminations (i.e. end caps) are places where jacketing can be installed improperly. Sometimes they can be omitted entirely with obvious CUI risks. In addition, end caps installed on vertical lines that are improperly sealed or without attention to shedding rainwater can lead to CUI problems (see Figure 31).

The final craftsmanship issue relates to storage and handling of insulation materials prior to installation. Insulation materials need to be stored in a dry location and need to be protected from exposure to rain and weather prior to

Figure 30—Examples of Joints with Poor Ability to Shed Water

Figure 31—Example of Missing End Cap

installation of the jacketing. Insulation materials stored on the ground without any water-resistant covering can lead to insulation being installed wet.

11.6 Mitigation of CUF Damage

Corrosion on structural members protected by fireproofing causes multiple problems. Initially, the trapping of water behind the fireproofing causes corrosion of the structural member. The steel corrosion products occupy a much greater volume than the uncorroded steel. This leads to cracks forming in the fireproofing that allow greater water ingress. In colder environments this can be exacerbated by the expansion that occurs as the water freezes.

There are several factors that promote CUF damage on vessel skirts and structural steel supports. Poor design of the fireproofing system can result in trapping water between the fireproofing and the underlying steel. Also, inadequate sealing of the fireproofing-to-steel termination joint may also allow water to be trapped behind the fireproofing. The lack of protective coatings on fireproofed substrates can contribute to rapid corrosion. Approaches to these issues include:

a) installation of weather shields to direct water away from fireproofing terminations,

b) painting fireproofed substrates for corrosion protection.

In addition to the above, it should be noted that when intumescent or subliming fireproofing compounds are used, the fireproofing manufacturer needs to provide a list of compatible coatings for use with their material. Also, inorganic zinc coatings used on their own are not effective coatings under fireproofing. Zinc is amphoteric and can be attacked in the alkaline conditions that exist beneath concrete and cementitious fireproofing.

11.7 Repair Techniques/Strategies

11.7.1 General

The repair of CUI on equipment and piping depends on the degree (i.e. severity) of damage of the component. When CUI is within the original corrosion allowance for the component, the repair strategy might be as simple as cleaning the corroded surface and repainting the affected area. When CUI damage is beyond the original corrosion allowance for the component, the repair strategy could be complex involving Fitness-For-Service (FFS) analysis along with section replacement or extensive weld buildup.

When developing an appropriate repair strategy, site personnel need to establish whether the repair will be temporary or permanent. As indicated API 510 and API 570, temporary repairs should be removed and replaced with a suitable permanent repair at the next available maintenance opportunity. Temporary repairs may remain in place for a longer period of time only if approved and documented as required by the appropriate API in-service inspection code.

11.7.2 Carbon and Low Alloy Steel Repairs

11.7.2.1 Surface Coatings

The use of surface coatings may be considered when CUI damage does not exceed the original corrosion allowance of the component. Any surface coating that is considered should be resistant to hot water immersion since the environment under insulation is very aggressive toward coatings. A key parameter in maximizing the life of a surface coating is the quality of the surface preparation and the cleanliness of the surface. NACE SP0198 lists typical coating systems used for carbon steel and austenitic/duplex stainless steel equipment and piping, along with:

— temperature range for each coating system,

— level of surface preparation requirements,

— surface profile requirements,

— recommended thickness range for prime, and

— topcoat.

11.7.2.2 Weld Repairs

When the wall loss of the component exceeds the original corrosion allowance, a FFS analysis should be considered. When a FFS analysis indicates that continued operation is not an acceptable option, the equipment or piping system should be removed from service in order to affect a repair. A typical repair strategy for a locally corroded area would be to restore the wall thickness by weld buildup of the damaged area. As with any weld repair, the damaged area needs to be cleaned and prepared for welding. Typically, these repairs are made while the equipment or piping system is not in service. An in-service repair is possible provided that necessary proper precautions for in-service welding are taken. An evaluation of the type of insulation adjacent to the welding area should be conducted to determine if it is flammable or has absorbed a flammable substance. It may be necessary to conduct a risk assessment as part of the development of the repair strategy.

11.7.2.3 Engineered Enclosures

Engineered enclosures are generally considered temporary repairs since there is no strength weld attaching the enclosure to the piping. They are engineered mechanical sleeves, boxes, or clamps filled with a variety of resin compounds to seal leaking pipes. These types of repairs encapsulate thinned or leaking sections and are often sealed by proprietary injected sealing compounds. As with all temporary repairs, they should be removed and replaced with a suitable permanent repair at the next available maintenance opportunity. Concerns regarding these methods include the following.

— Engineered enclosures may not be suitable when the system is subject to significant thermal cycling.

— Consider the need to reinject after plant upset.

— Engineered enclosures can be bulky and heavy.

— External support may be needed to avoid overstressing the system (ensure allowance is made for thermal cycling).

— Generally this form of clamp will only restore the ability of the piping system to withstand internal pressure and hence may not protect against failure due to external loading if the system is corroded below the minimum required thickness.

— Proprietary design and calculation techniques should be verified by the owner/operator’s design engineer.

— The sealant is applied at the point of contact with the parent metal.

— It generally requires a reasonable degree of surface cleanliness at the sealant contact points. This can be difficult to achieve if the surface is substantially pitted and corroded externally, so the box may be very large in order to extend to an area that is not corroded.

— Boxes that are fixed to the line by clamping between flange pairs are usually successful.

— However, boxes that are fixed to bare pipe surfaces and rely on the sealant properties of the injected compound sometimes fail to achieve tight seals. They will, however, reduce the leakage to atmosphere to a level that may be considered sustainable in the short term. Improved results can be obtained using gland material as a secondary sealant.

A log of all engineered enclosures should be maintained by the site.

11.7.2.4 Composite Wraps

An alternative repair strategy for piping with CUI damage is the use of composite wrap systems. There are a variety of these systems ranging from fiberglass/polymer systems, woven carbon fiber/polymer systems, and systems that are a combination of fiberglass, carbon fiber, and polymer. These wraps protect and structurally reinforce the corroded pipe in the same manner as steel sleeves. The strain is transferred into the composite wrap, and pipe deformation is effectively constrained. Using this approach, the undamaged material around the corroded area is cleaned to achieve a good surface finish to adhere the composite wrap. An incompressible filler is essential to ensure that all of the plastic deformation of the pipe’s thinner wall section is directly transferred into the composite repair. The deeper the corrosion, the greater the possible membrane bulging, it is therefore essential to ensure the filler is incompressible. Adhesive is applied to the pipe surface to provide good bonding with the wrap material. In some cases, the wrap is fabricated composite sleeve wound around the pipe. In other instances, the cleaned area is encapsulated by a steel sleeve, and the sleeve is then filled with a resin material to bond the sleeve to the pipe when cured.

The pressure/temperature limits for these wraps are dependent on the type of damage being repaired and the repair system being used. The limits for each of these systems are determined by the testing and qualification requirements outlined in ASME PCC-2 and ISO 24817. As such it is classed as an engineered repair, both reference documents are based on the same source-work and broadly equivalent. They require the system to have undergone a series of validation tests and use the data measured to assess each repair for the given set of design conditions. The documents require a set of calculation to be completed that determine the thickness of repair required. In principle each repair should be individually designed.

11.7.2.5 Pipe Clamps

Compression clamps have been in general use in the industry for sealing isolated pitting leaks. These types of clamps may be applied to temperatures in excess of 175 °F (80 °C), and they can be rated to high pressures. Since these clamps rely on compressing the parent pipe, it is essential to confirm that the remaining wall thickness is adequate to withstand the compressive forces that will be applied.

11.7.3 Austenitic and Duplex Stainless Steels

11.7.3.1 Crack Removal

If ECSCC cracking is not extensive and is within the original corrosion allowance for the component, it can be removed by blend grinding with the adjacent material. Milling and other similar techniques can also be used to remove cracks. Blend ground areas should be examined by the liquid penetrant examination (PT) or eddy current examination (ET) methods to determine whether all cracks have been removed from the surface. Blend ground areas should be aluminum wrapped or coated after the repair is performed.

11.7.3.2 Patch or Insert Plate Repairs

Patch or insert plates may be considered as repair strategies if cracking is not extensive. The undamaged area should be inspected by ET. After assessing the extent of damage using ET, the material containing ECSCC damage should be removed and prepared for welding. Prior to welding, the material adjacent to the area planned for repair should be reinspected using ET to ensure that no cracking has occurred as a result of the material removal and weld preparation process (i.e. because of stresses associated with cutting/grinding). It may be necessary to consult a FFS specialist prior to repair. Repairs should be aluminum wrapped or coated after the repair is performed.

11.7.3.3 Partial Replacement

When ECSCC cracking is extensive but confined to one particular area [i.e. such as the upper portion of a column that operates below 350 °F (175 °C)], partial replacement of equipment could be considered as the possible repair strategy. In the example cited, the upper portion of the column could be replaced. Partial replacement of a column can be very costly. As a result, the cost effectiveness of this approach needs to be compared to other possible alternate repair strategies.

11.7.3.4 Complete Replacement

Obviously, replacement of an entire vessel or piping system is an extreme approach to resolving a CUI problem. The decision to replace equipment or piping should only be considered after a thorough review of the economic cost and other impacts of all repair strategy options.

11.8 Safety Issues

11.8.1 General

Safety precautions are important in during maintenance or inspection activities because some process fluids are harmful to human health. Any maintenance, inspection, or repair work on in-service equipment poses hazards that need to be risk assessed prior to initiation of the activity. When conducting these activities, personnel should review the site safety procedures prior to the initiation of work. A leak or failure in a piping system may be only a minor inconvenience, or it may become a potential source of fire or explosion, depending on the temperature, pressure, contents, and location of the piping. Piping in a petrochemical plant may carry flammable fluids, acids, alkalis, and other harmful chemicals that would make leaks dangerous to personnel.

11.8.2 Maintenance/Cleaning Hazards

11.8.2.1 General

There are potential risks associated with the removal of the jacketing and insulation. The removal of the insulation from in-service piping potentially exposes hot metal surfaces. If personnel contact the hot (or cold) surface, they may be exposed to injury (i.e. burns). Removal of surface scale on piping can also lead to a process leak if the CUI damage is significant. This would expose personnel to the leakage of hot fluids.

In addition to these hazards, there are other concerns related to how scale is removed from the surface of the component. Cleaning personnel need to be careful to avoid coming in contact with blasting grit or debris from the cleaning process. Personnel performing hydroblasting should avoid contact with high-pressure water when removing external corrosion scale.

11.8.2.2 Asbestos and Lead Coating Removal

Surfaces coated with lead-based coatings or insulated with asbestos also require special precautions and experienced contractors when being removed from surfaces with CUI damage. Before any work with asbestos or lead coating is carried out, OSHA regulations (29 *CFR* Part 1910.1001) require employers to make an assessment of the likely exposure of employees to asbestos and lead dust, including providing a description of the precautions that need to be taken to control dust to protect workers and others from exposure.

11.8.3 Inspection Hazards

11.8.3.1 General

In order to assess the condition of the piping, it is often necessary for personnel to be able to see the clean pipe surface. This necessitates removal of the scale from the pipe surface. Often this is done using either a file or a flapper wheel. There have been instances where minimal removal of surface scale has caused a hole in the piping. When equipment is in operation, it is necessary to evaluate the risks associated with preparing the surface prior to inspection. Removing scale on thinned piping can expose inspection personnel to hot process fluid. Often, inspection personnel will inspect piping for thinned areas by tapping a hammer on the surface of the piping. Thinned areas will sound different than areas that are thicker. Here too, areas that are corroded may develop a hole from hammering if they are severely thinned, exposing inspection personnel to hot process fluid. This should not be done on operating equipment.

When equipment is in operation, it is necessary to evaluate the risks associated with preparing the surface prior inspection. Removing scale on thinned piping can expose inspection personnel to hot process fluid.

11.8.3.2 Work on Operating Equipment

Intrusive work on operating equipment should be performed only after careful review. Often it is very difficult to assess the condition of insulated equipment for CUI damage. It may be necessary to use several inspection techniques to minimize exposures. When it is necessary to remove corrosion product, some things to consider include the thickness of the scale, remaining corrosion allowance, and inspection effectiveness. Activities such as sandblasting and scraping areas with heavy scale should be avoided on live equipment. When that is impractical, a job hazards review should be considered. An epoxy coating of equipment with a scale sealing paint may be desired until a shutdown window can be met.

Annex A
(informative)

Examples of a Qualitative Likelihood Assessment System

A.1 General

There are a variety of approaches and methodologies that can be employed in conducting likelihood assessments. Shown below is a simplistic approach to demonstrate how a points-based approach might be employed and is presented only as an example. When utilizing a points-based approach, the relative weighting of each factor, or additional factors impacting CUI or CUF damage at a site, should be based on site experience.

A.2 CUI Assessment for Carbon and Low Alloy Steels

Parameter Rating

Parameter	0	1	3	5
Operating Temperature		25 °F to 100 °F or 270 °F to 350 °F (–4 °C to 38 °C or 132 °C to 177°C)	100 °F to 170 °F or 230 °F to 270 °F (38 °F to 77 °F or 110 °C to 132 °C)	170 °F to 230 °F or cyclic service from >350 °F to <230 °F (77 °C to 110 °C or cyclic service from >177 °C to <110 °C)
Coating/Age	Quality coating within 8 yeas or system age <15 years	Quality coating within 15 years or system age <30 years	General coating 8 to 15 years	General coating age >15 years, system age >30 years, or unknown
Jacketing/ Insulation Condition	System age <5 years without deficiencies	Average condition with good maintenance (such as sealed, no gaps, CML ports with plugs)	Average condition with some deficiencies	Damaged condition with several deficiencies
Heat Tracing	None	High-integrity steam system or electric tracing	Steam system with medium integrity	Steam system with visible leaks
External Environment	No sweating	Arid and inland	All other locations	Coastal/marine, cooling tower overspray, or local external water source exposure (deluge systems, dripping steam condensate)
Insulation Type	Insulating coating	Expanded perlite, foam glass, closed-cell foam	Fiberglass, perlite, mineral fiber. Insulation has <10 ppm Cl	Calcium silicate, mineral fiber with >10 ppm Cl, or unknown
Line Size or Nozzle Size	Equipment	>6 in.	>2 in. to 6 in.	≤2 in.

Likelihood Rating

Parameter Rating Total	<7	7 to <14	14 to 20	>20 to 27	>27
Likelihood Rating	A	B	C	D	E

NOTE System age is defined as the time since last insulation/jacketing installation or replacement.

A.3 CUI Assessment for Austenitic and Duplex Stainless Steels

Parameter Rating

Parameter	0	1	3	5
Operating Temperature		120 °F to 140 °F (47 °C to 60 °C)	250 °F to 400 °F (121 °C to 204 °C)	140 °F to 250 °F (60 °C to 121 °C)
Coating/Age	Quality coating within 8 years	Quality coating within 15 years	General coating 8 to 15 years	General coating >15 years or unknown
Jacketing/ Insulation Condition	No deficiencies	Average condition with good maintenance (such as sealed, no gaps, CML ports with plugs)	Average condition with some deficiencies	Damaged condition with several deficiencies
Heat Tracing	None	High-integrity steam system or electric tracing (Cl-free covering)	Steam system with medium integrity	Steam system with visible leaks or electrical with PVC covering
External Environment	No sweating	Arid and inland	All other locations	Coastal and marine, cooling tower overspray, or external water source exposure (deluge systems, dripping steam condensate)
Insulation Type	Insulating coating	Expanded perlite, foam glass, closed-cell foam	Fiberglass, perlite, mineral fiber. Insulation has less than 10 ppm Cl	Calcium silicate, mineral fiber with >10 ppm Cl, or unknown
Line Size or Nozzle Size	Equipment	>6 in.	>2 in. to 6 in.	≤2 in.

Likelihood Rating

Parameter Rating Total	<7	7 to <14	14 to 17	>20 to 27	>27
Likelihood Rating	A	B	C	D	E

NOTE Duplex stainless steels are more resistant to ECSCC, and it may be warranted to increase parameter rating.

A.4 CUF Assessment

Parameter Rating

Parameter	0	1	3	5
Operating Temperature		120 °F to 140 °F (47 °C to 60 °C)	250 °F to 400 °F (121 °C to 204 °C)	140 °F to 250 °F (60 °C to 121 °C)
Coating/Age	Quality coating within 8 years or system age <15 years	Quality coating within 15 years or system age <30 years	General coating 8 to 15 years	General coating >15 years, system age >30 years, or unknown
Fireproofing Condition	System age <5 years without deficiencies	Average condition with good maintenance	Average condition with cracking evident	Damaged condition
Potential for Water Ingress	None	—	—	Design allows for water ingress/travel from above
External Environment	No sweating	Arid and inland	All other locations	Coastal and marine, cooling tower overspray, or external water source exposure (deluge systems, dripping steam condensate)
Material Type	Intumescent coating	Cementitious	—	Calcium silicate, mineral fiber insulation

Likelihood Rating

Parameter Rating Total	<7	7 to <12	12 to 16	>16 to 19	>19
Likelihood Rating	A	B	C	D	E

NOTE System age is defined as the time since last insulation/jacketing installation or replacement.

Annex B
(informative)

Examples of Insulation Techniques for Various Applications

B.1 General

Shown below are a variety of designs to insulate a variety of components.

B.1.1 Cold Service Applications

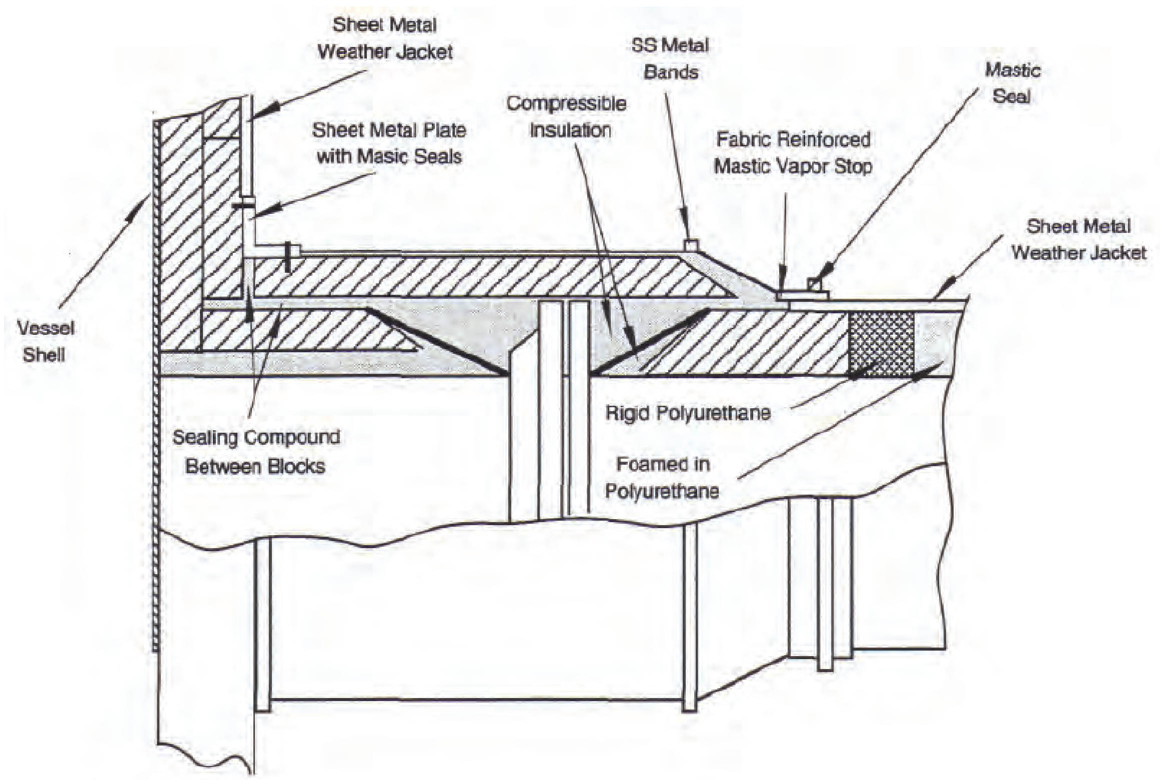


Figure B.1—Method of Insulating Nozzles and Manways

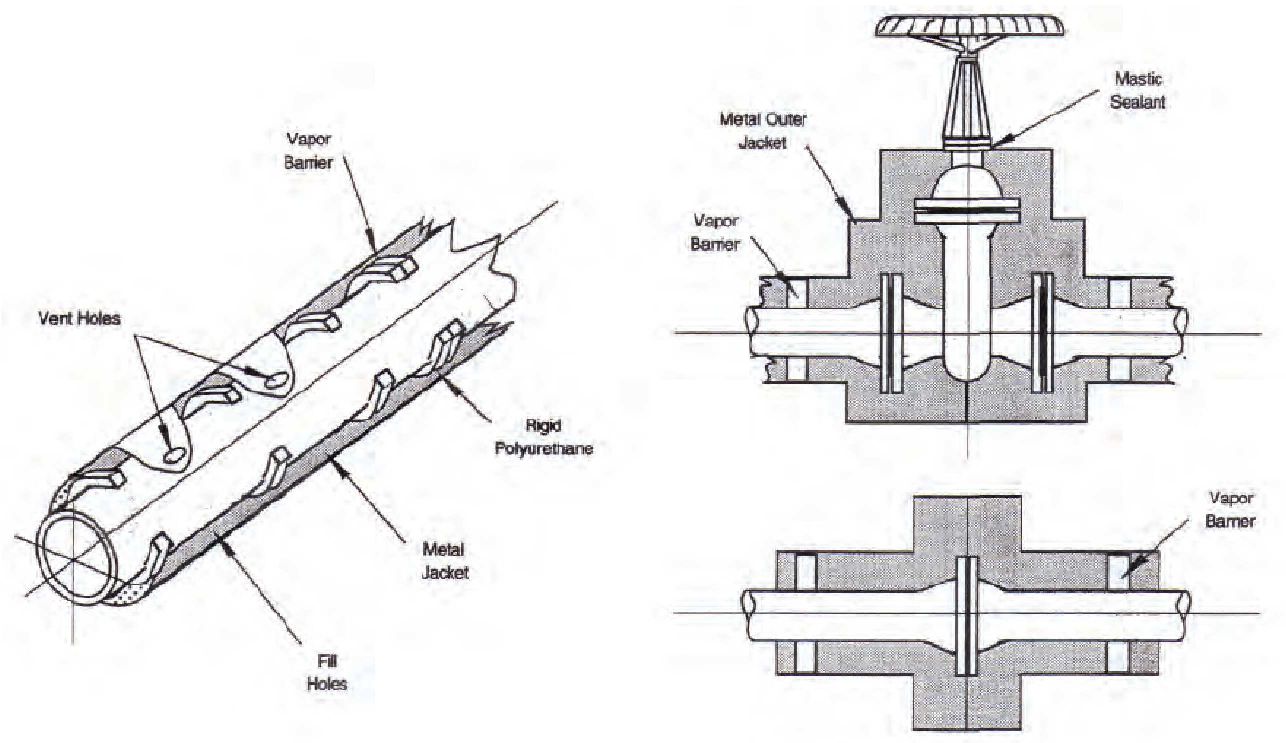


Figure B.2—Method for In Situ Polyurethane Foaming of Straight Pipe and Valve/Flange Boxes

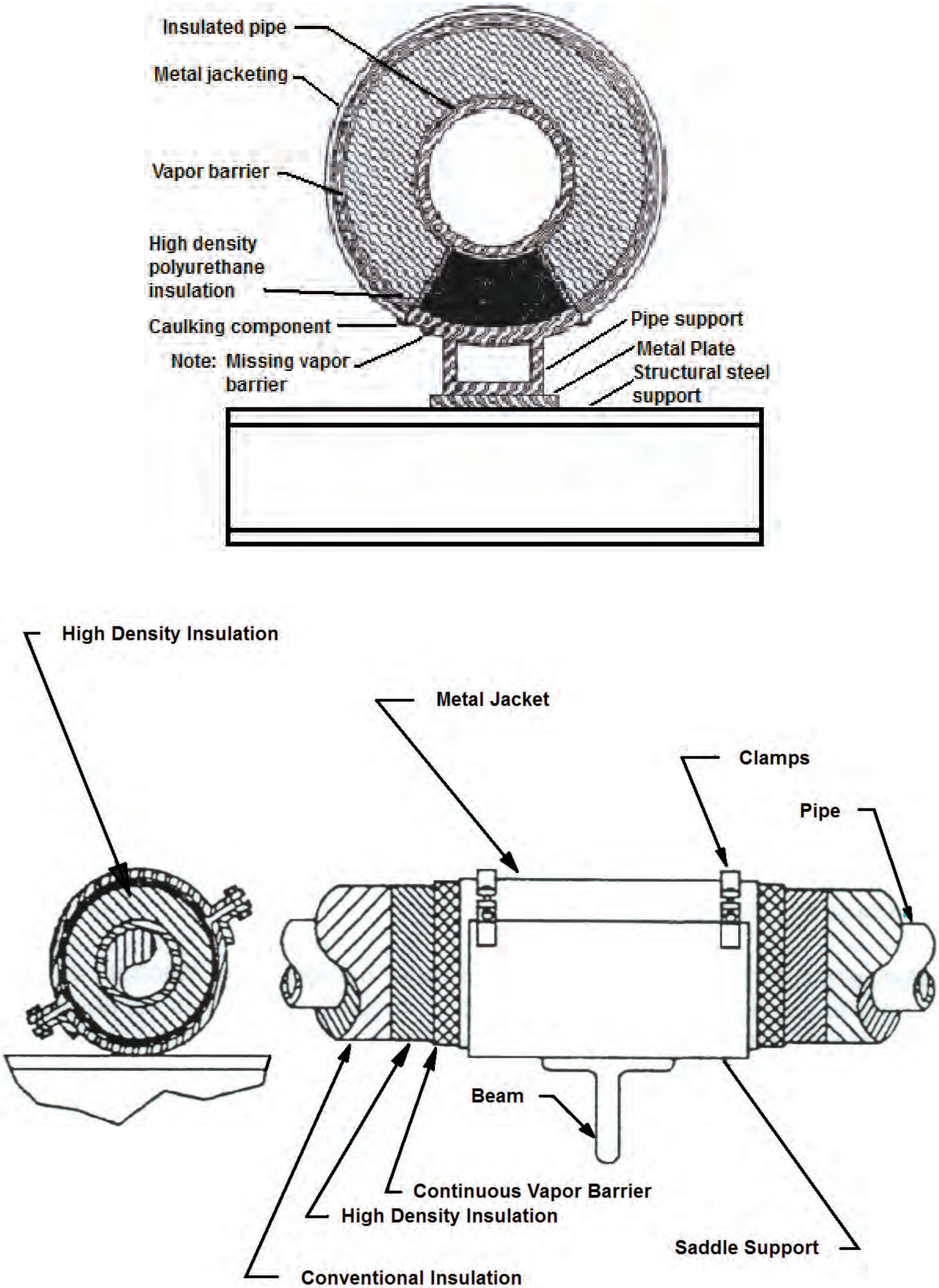


Figure B.3—Method for Insulating Pipe Support with and Without Continuous Vapor Barrier

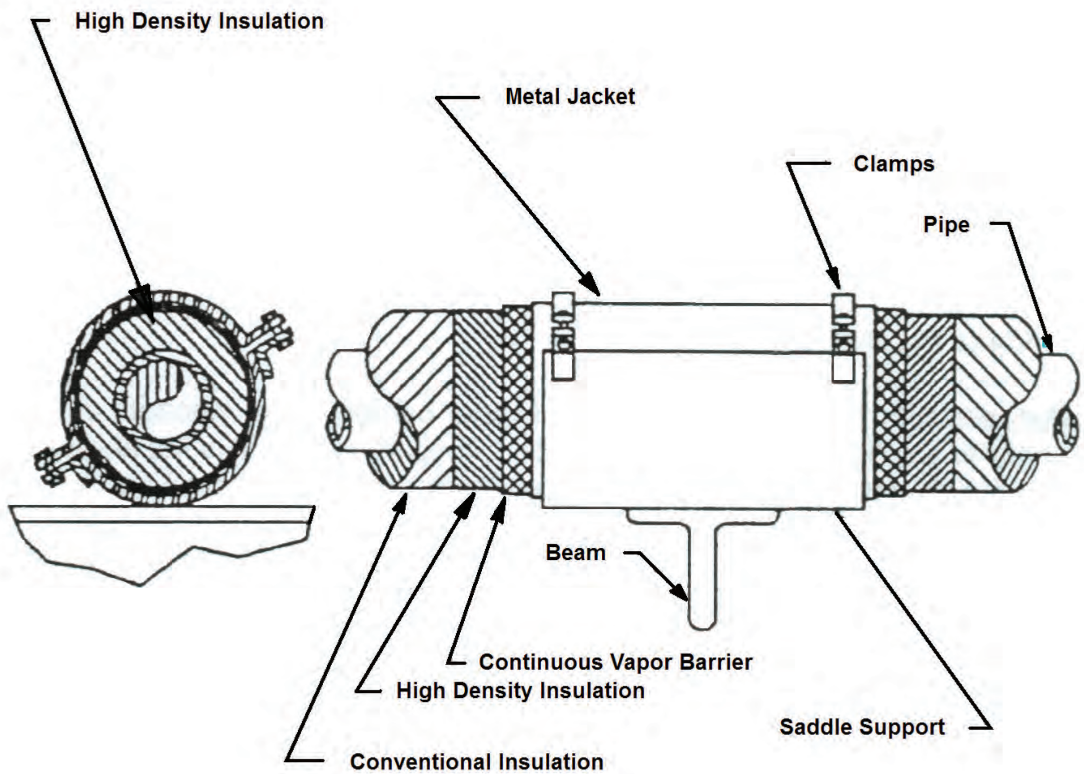


Figure B.4—Method for Insulating Miscellaneous Attachments

B.1.2 Hot Service Applications

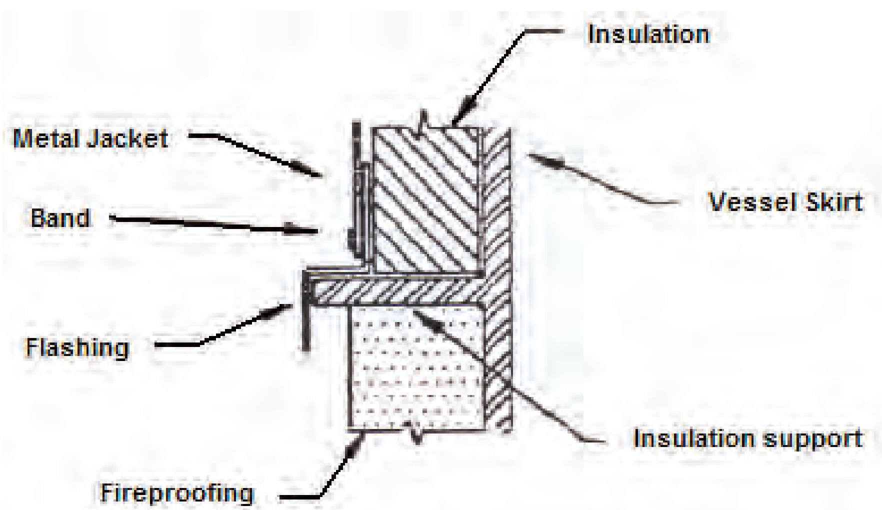


Figure B.5—Method for Insulating Vertical Vessel Bottom Support Ring

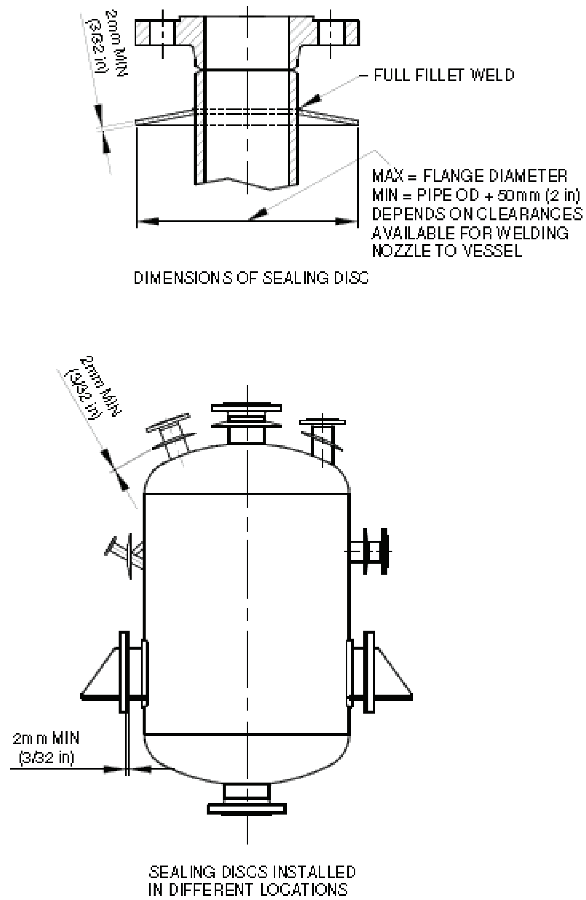


Figure B.6—Method of Diverting Water Away from Critical Locations

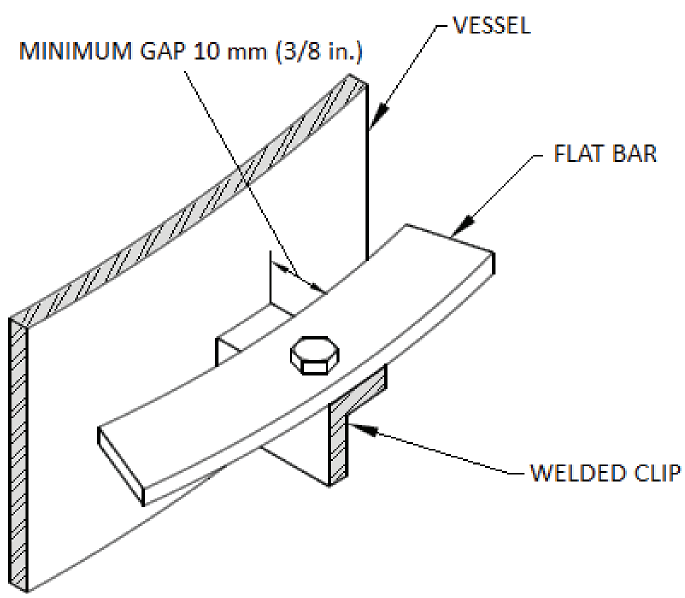


Figure B.7—Method of Avoiding Water Buildup at Insulation Supports

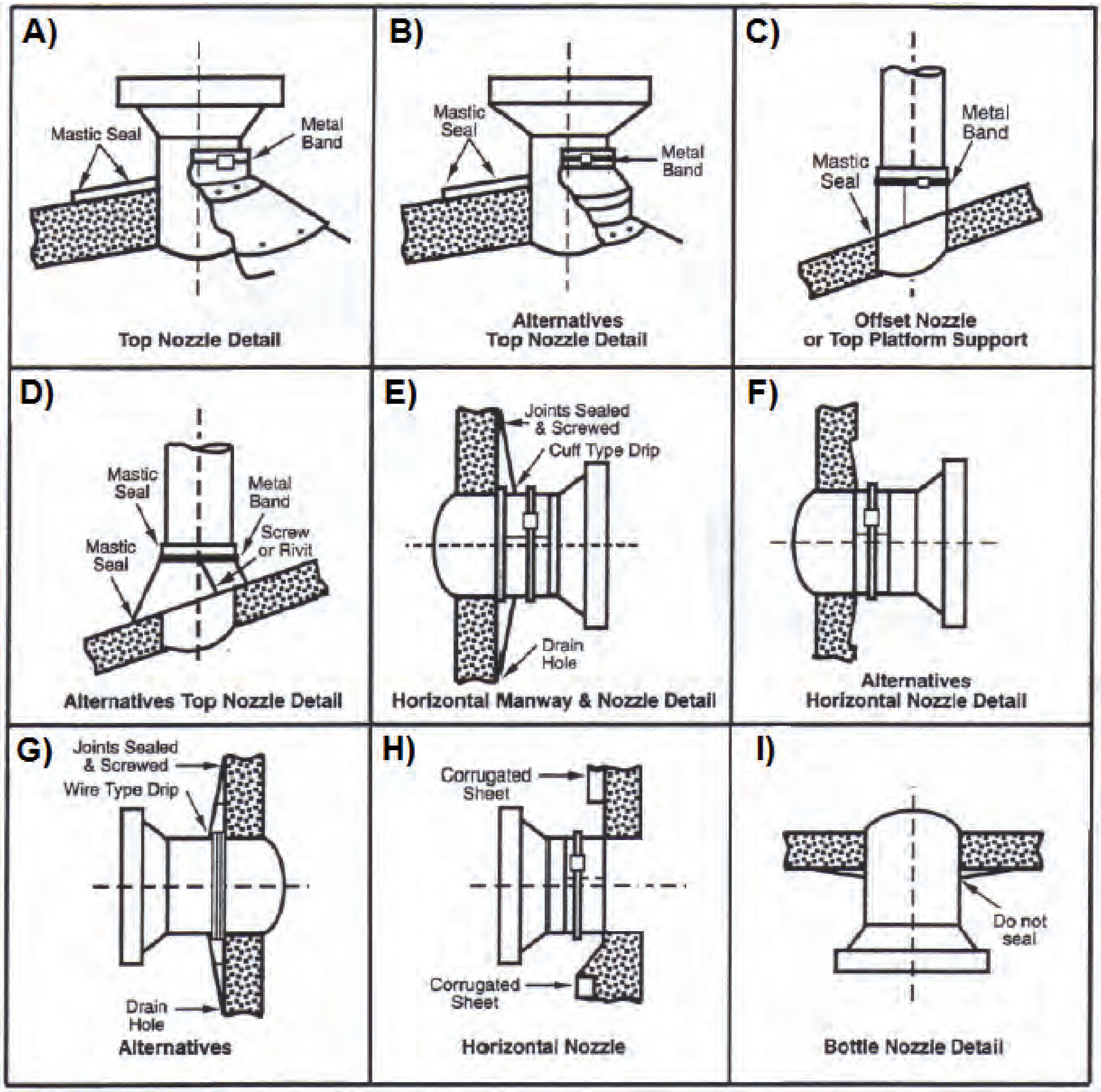


Figure B.8—Method of Avoiding Water Buildup for Vessel Nozzles and Attachments

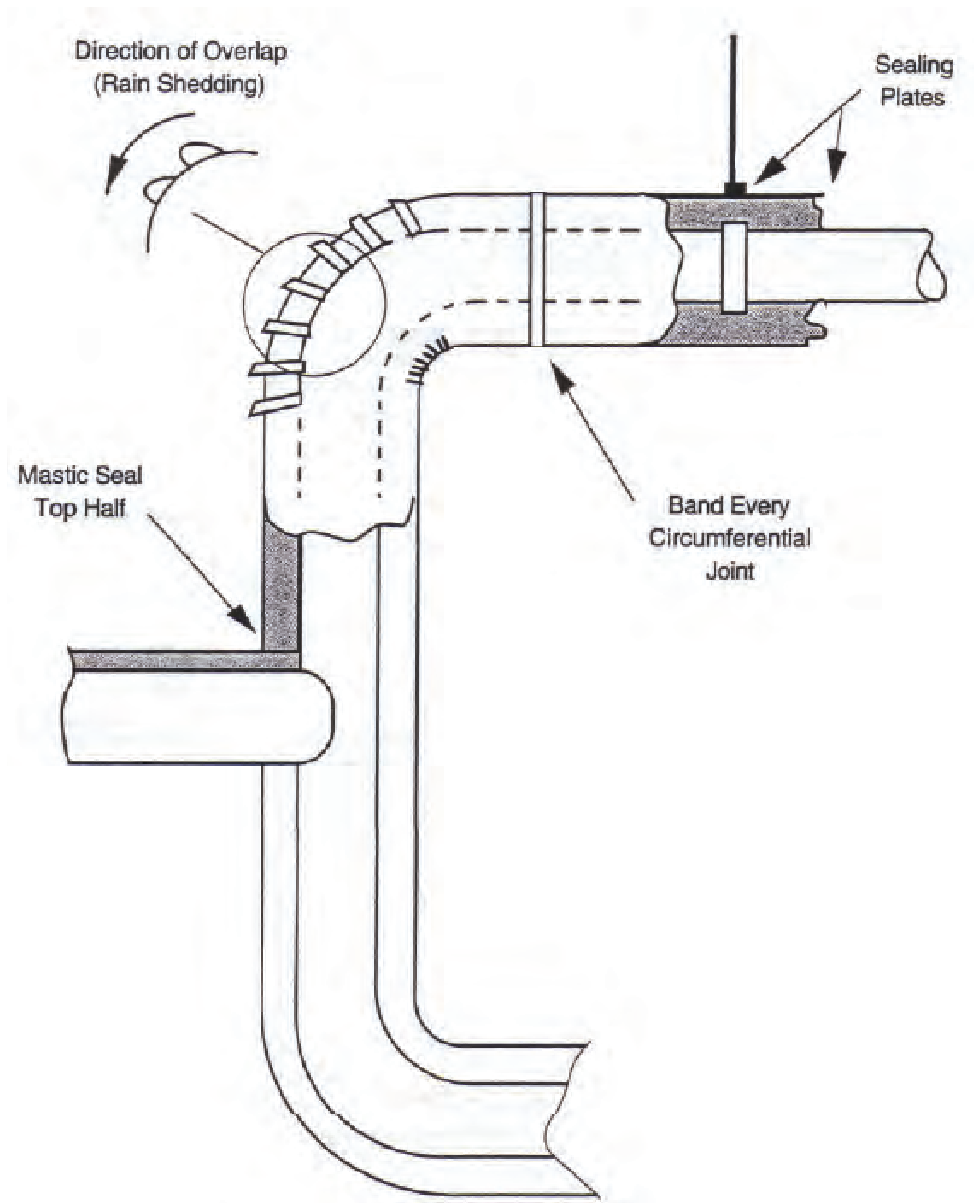


Figure B.9—Method of Avoiding Water Buildup for Piping

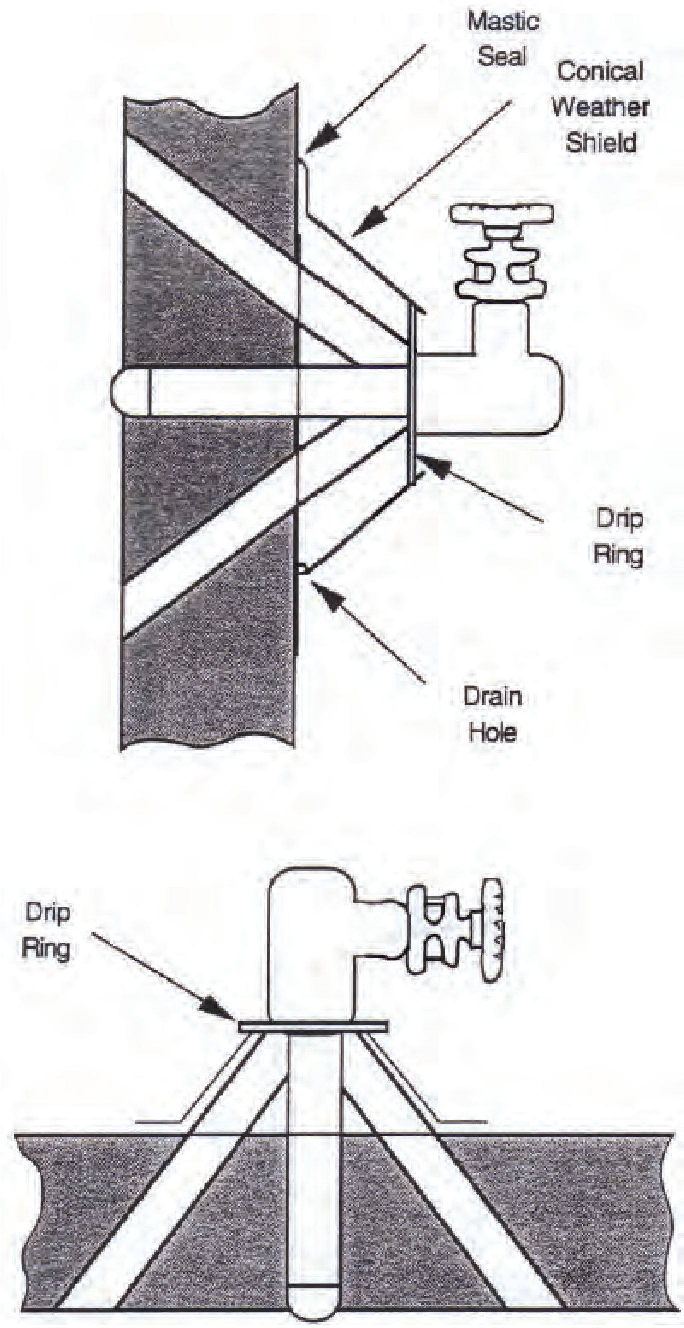


Figure B.10—Method of Avoiding Water Buildup for Horizontal and Vertical Gussets

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