

Control of Corrosion Under Thermal Insulation and Fireproofing Materials

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ABSTRACT

Provides current technology and industry practices for mitigating corrosion under thermal insulation and fireproofing materials. Adopts a systems approach. Contains sections on corrosion mechanisms, mechanical design, protective coatings, insulation materials, and inspection and maintenance.

KEYWORDS

carbon steels, coatings, corrosion control, fireproofing materials, insulation, protective coatings, steels, thermal insulation, TG 325

Foreword

In NACE standards, the terms shall, must, should, and may are used in accordance with the definitions of these terms in the NACE Publications Style Manual. The terms shall and must are used to state a requirement, and are considered mandatory. The term should is used to state something good and is recommended, but is not considered mandatory. The term may is used to state something considered optional.

This NACE standard practice provides the current technology and industry practices for mitigating corrosion under thermal insulation and fireproofing materials, a problem termed *corrosion under insulation (CUI)* in this standard. Because this corrosion problem has many facets and impacts several technologies, a systems approach has been adopted. This standard is intended for use by corrosion-control personnel and others concerned with corrosion under insulation and/or fireproofing of equipment.

This standard is organized into sections by function. Each section was written by specialists in that subject. These specialists are industry representatives from firms producing, specifying, designing, and/or using thermal insulation and fireproofing products on refinery and petrochemical equipment.

This standard was originally prepared in 1998 by NACE Work Group T-5A-30a, "Corrosion Protection Under Insulation," with the assistance of Task Group (TG) T-6H-31, "Coatings for Carbon and Austenitic Stainless Steel Under Insulation," and ASTM⁽¹⁾ Committee C16.40.3, "Corrosion Under Insulation." Work Group T-5A-30a supported NACE TG T-5A-30, "Corrosion Under Thermal Insulation," a component of NACE Unit Committee T-5A, "Corrosion in Chemical Processes." The standard was reaffirmed in 2004 by Specific Technology Group (STG) 36, "Process Industry: Materials Performance in Chemicals." It was revised in 2010 by TG 325, "CUI: Revision of NACE Standard RP0198, The Control of Corrosion Under Thermal Insulation and Fireproofing Materials—A Systems Approach," with the assistance of Technology Exchange Group (TEG) 255X, "Coatings, Thermal-Spray for Corrosion Protection." It was reaffirmed in 2016 by TG 325, "CUI: Revision of NACE SP0198 (formerly RP0198), "The Control of Corrosion Under Thermal Insulation and Fireproofing Materials—A Systems Approach." TG 325 is administered by STG 36 and sponsored by STG 03, "Coatings and Linings, Protective—Immersion and Buried Service," and STG 04, "Coatings and Linings, Protective—Surface Preparation." This standard is issued by NACE International under the auspices of STG 36.

⁽¹⁾ ASTM International (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

Control of Corrosion Under Thermal Insulation and Fireproofing Materials

1.	General	4
2.	Corrosion Mechanisms	5
3.	Mechanical Design	12
4.	Protective Coatings	16
5.	Insulation, Fireproofing, and Accessory Materials	20
6.	Inspection and Maintenance	25
	References	32
	Bibliography	33

Figures and Tables

Figure 1: Effect of Temperature on Steel Corrosion in Water	6
Figure 2: Typical Vessel Attachments Where Water May Bypass Insulation	13
Figure 3: Attachment to Piping Where Water May Bypass Insulation	13
Figure 4: Vessel Insulation Support Ring—the Problem (a) and the Solution (b) ..	14
Figure 5: Vertical Vessel Bottom Support Ring Minimizing Water Accumulation ...	14
Figure 6: Vessel-Stiffening Ring Insulation Detail	14
Figure 7: Center Nozzle at Top Head of Vessel	15
Figure 8: Common Nameplate Insulation Detail	15
Figure 9: Seal-Welded Cap on Insulation for Personnel Protection	15
Figure 10: Double-Pipe Heat Exchanger Insulation Penetrated by C-Channel Support	15
Figure 11: Protrusions Through Jacketing	16
Figure 12: Pipe Supports Without Protrusions	16
Figure 13: Cold Service Pipe Support Without Continuous Vapor Barrier	16
Figure 14: Cold Service Pipe Support with Continuous Vapor Barrier	17
Figure 15: Pipe Insulation Penetrated by Column Fireproofing	17
Table 1: Typical Protective Coating Systems for Austenitic and Duplex Stainless Steels Under Thermal Insulation	18
Table 2: Typical Protective Coating Systems for Carbon Steels Under Thermal Insulation and Fireproofing	19

Section 1: General

- 1.1 Corrosion under insulation (CUI) has been occurring for as long as hot or cold equipment has been insulated for thermal protection, energy conservation, or process stabilization. The destructive results and nature of the corrosion mechanism were not mentioned in the literature until the 1950s. As more problems have been experienced, concern and interest have built around this subject. Many articles and symposium papers have been published since 1983 as interest and activity in CUI have increased. The increased activity was driven largely by many occurrences of severe CUI resulting in major equipment outages, production losses, and unexpected maintenance costs in refineries, gas plants, and chemical plants.
- 1.2 To correct these problems, companies have developed their own criteria and approaches to the prevention of CUI. When comparing the various approaches, it is evident that there are many similarities, some differences, some new ideas, and some old ideas that have stood the test of performance. This standard incorporates the experience of many companies throughout the oil, gas, and chemical industries.
- 1.3 The first ASTM standard relevant to CUI was ASTM C692,¹ adopted in 1971 and originally titled "Evaluating the Influence of Wicking Type Thermal Insulations on the Stress Corrosion Cracking Tendency of Austenitic Stainless Steels."
- 1.4 A symposium was held jointly by NACE, ASTM, and Materials Technology Institute (MTI)⁽²⁾ on this subject with speakers from industries worldwide in October 1983. The papers were published in 1985 as ASTM Publication STP 880.²
- 1.5 The first NACE state-of-the-art report on CUI was written in 1989 by Task Group T-6H-31 and issued as NACE Publication 6H189.³ NACE Task Group T-5A-30 was organized shortly thereafter to serve as a forum for further discussion regarding CUI. In addition to reviews of the corrosion mechanisms, perspectives on such CUI topics as methods for mitigation, insulation materials, and inspection were often exchanged. While corrosion engineers were becoming knowledgeable about CUI, ASTM Committee C16 on Thermal Insulation was preparing standards for testing insulation with a propensity to cause chloride stress corrosion cracking (SCC) of austenitic stainless steel. These two groups interacted but proceeded to develop their standards and information separately.
- 1.6 In this standard, the term *equipment* includes all objects in a facility with external metal surfaces that are insulated or fireproofed and subject to corrosion.
- 1.7 In previous editions of this standard, carbon steel and austenitic stainless steels were the primary metals addressed. Because of their increased usage in applications where CUI is a concern, duplex stainless steels have been more explicitly addressed in this revision.
- 1.8 Although most of the attention has been focused on corrosion under thermal insulation, fireproofing materials also function, at least in part, as insulation applied to protect equipment during a potential fire. Other fire protection mechanisms initiated as endothermic reactions within the fireproofing material during a fire are not covered in this standard. Corrosion mechanisms, the root cause of failure, and corrosion prevention are the same for corrosion under fireproofing as for corrosion under insulation.

⁽²⁾ Materials Technology Institute (MTI), 1215 Fern Ridge Parkway, Suite 206, St. Louis, MO 63141-4405.

- 1.9** Whenever CUI is a consideration, a protective coating or coating system should be applied to the equipment before it is insulated. Protective coatings or coating systems may have service lives that are shorter than the anticipated operational life of the equipment, and thus may require inspection and maintenance to effectively maintain integrity and to minimize the threat of CUI.

Section 2: Corrosion Mechanisms

2.1 Carbon Steel

Carbon steel corrodes, not because it is insulated, but because it is contacted by aerated water. The role of insulation in the CUI problem is threefold. Insulation provides:

- (a) An annular space or crevice for the retention of water and other corrosive media;
- (b) A material that may wick or absorb water; and
- (c) A material that may contribute contaminants that increase the corrosion rate.

The corrosion rate of carbon steel may vary because the rate is controlled largely by the metal temperature of the steel surface and contaminants present in the water. These factors and others are reviewed below.

2.1.1 Effects of Water, Contaminants, and Temperature

2.1.1.1 Sources of Water Under Insulation

The two primary water sources involved in CUI of carbon steel are:

- (a) Infiltration from external sources; and
- (b) Condensation.

Water infiltrates from such external sources as the following:

- (a) Rainfall;
- (b) Drift from cooling towers;
- (c) Condensate falling from cold service equipment;
- (d) Steam discharge;
- (e) Process liquids spillage;
- (f) Spray from fire sprinklers, deluge systems, and washdowns;
- (g) Groundwater; and
- (h) Condensation on cold surfaces after vapor barrier damage.

External water enters an insulated system primarily through breaks in the weatherproofing. The weatherproofing breaks may be the result of inadequate design, incorrect installation, mechanical abuse, or poor maintenance practices.

Condensation results when the temperature of the metal surface is lower than the atmospheric dew point. Although infiltration of external water can be reduced and sometimes prevented, insulation systems cannot be made vapor tight, so condensation as a water source must be recognized in the design of the insulation system.

2.1.1.2 Contaminants in Water Under Insulation

Contaminants can increase the conductivity and/or corrosiveness of the water environment. There are two primary classes of contaminants in water under insulation:

- (a) Contaminants external to the insulation materials; and
- (b) Contaminants leached from the insulation materials.

Chlorides and sulfates are the principal contaminants found under insulation. Whether their source is external or internal, they are particularly detrimental because their respective metal salts are highly soluble in water, and these aqueous solutions have high electrical conductivity. In some cases, hydrolysis of the metal salts can cause localized corrosion because of development of low pH in anodic areas.

External contaminants are generally salts that come from sources such as cooling tower drift, acid rain, firewater deluge, and atmospheric emissions. The external contaminants are waterborne or airborne and can enter the insulation system directly through breaks in the weatherproofing. External contaminants also enter the insulation materials indirectly by depositing on the jacket surface. Subsequent wetting then carries the concentrated salts to breaks in the weatherproofing. The salts enter the insulation system by gravity or the wicking action of absorbent insulation. The salt concentrations gradually increase as water evaporates from the carbon steel surface.

Contaminants contained in the insulation materials are well documented. Chloride is generally one of the contaminants, unless the insulation product is declared “chloride free.” Chlorides can be present in almost all components of the insulation system, including the insulation, mastic, and sealant. As water enters the insulation system, the contaminants are leached from the material and concentrate as water evaporates from the carbon steel surface. If the insulation materials contain water-leachable acidic compounds, the pH of the water is lowered, resulting in increased corrosion.

2.1.1.3 Effect of Temperature

Service temperature is an important factor affecting CUI of carbon steel because two opposing factors are involved:

- (a) Higher temperature reduces the time water is in contact with the carbon steel; however,
- (b) Higher temperature tends to increase the corrosion rate and reduce the service life of protective coatings, mastics, and sealants.

Figure 1 illustrates the corrosiveness of water versus temperature. In an open system, the oxygen content of the water decreases as the temperature increases.⁴ However, at a temperature above approximately 80 °C (176 °F), the corrosion rate of carbon steel in aerated water begins to decrease with increasing temperature. In a closed system, the corrosion rate of carbon steel in water continues to increase as the water temperature increases.⁴ Field measurements of the corrosion rate of carbon steel corroding under insulation confirm that the corrosion rate increases with temperature in a manner similar to that of a closed system.⁵ This is relevant to the corrosion mechanism occurring under insulation, where the thin film of water, although not under pressure, is oxygen-saturated.

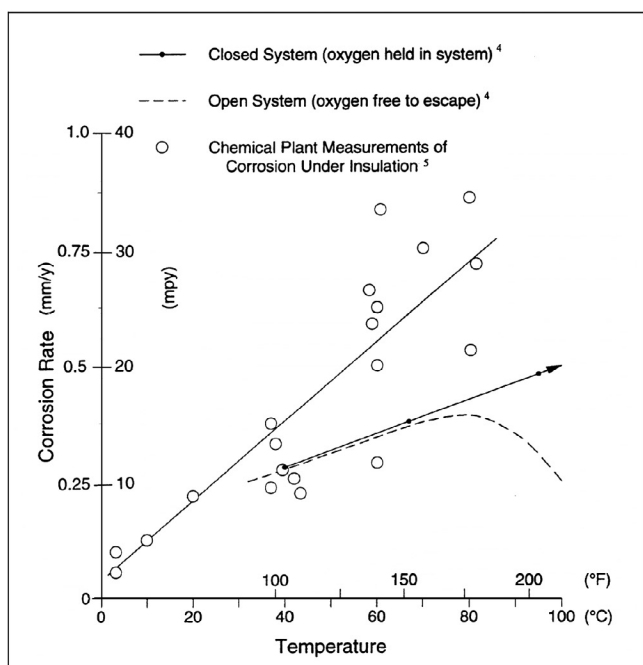


Figure 1: Effect of Temperature on Steel Corrosion in Water

Thus, the same oxygen cell corrosion mechanism is taking place as in a closed system. The corrosion rates from field measurements are somewhat greater than laboratory rates, because of the airborne or insulation-carried salts in the field. Such salts can influence the corrosion rate because of their high solubility in water and the attendant increase in the conductivity of the water film.

Field experience has shown many instances of CUI on equipment operating at temperatures up to 175 °C (350 °F), and it has been recognized within industry that carbon steel operating with a skin temperature in the temperature range of –4 °C (25 °F) to 175 °C (350 °F) has the greatest likelihood of CUI. Equipment that operates continuously below –4 °C (25 °F) usually remains free of corrosion. Corrosion of equipment operating above 175 °C (350 °F) is reduced because the carbon steel surface is warm enough to remain dry. However, corrosion tends to occur at those points of water entry into the insulation system where the temperature is below 175 °C (350 °F) and when the equipment is idle.

The service temperature of equipment often varies, and the corrosion rate of carbon steel under insulation is affected by:

- (a) Intermittent or variable (cyclic service) operation of equipment;
- (b) Temperature variations along the height or length of the equipment;
- (c) Temperature at which attachments to equipment operate; and
- (d) Idle or mothballed conditions.

See Paragraph 2.2 for information on these factors with regard to austenitic and duplex stainless steels.

2.1.2 Effects of Insulation Material

2.1.2.1 Effects of Types of Insulation

CUI of carbon steel is possible under all types of insulation. The insulation type may only be a contributing factor. The insulation characteristics with the most influence on CUI are:

- (a) Water-leachable salt content in insulation, such as chloride, sulfate, and acidic materials in fire retardants that may contribute to corrosion;
- (b) Water retention, permeability, and wettability of the insulation; and
- (c) Foams containing residual compounds that react with water to form hydrochloric or other acids.

Because CUI is a product of wet metal exposure duration, the insulation system that holds the least amount of water and dries most quickly should result in the least amount of corrosion damage to equipment.

Corrosion can be reduced by careful selection of insulation materials. Materials that may be cheaper on an initial cost basis may not be more economical on a life-cycle basis if they allow corrosion. For more detailed information about insulation materials, refer to Section 5.

2.1.2.2 Role of Weather Barrier and Vapor Barrier Materials

Weather barriers and vapor barriers are applied to insulation to keep the insulation dry. Mastics and sealants are materials used to close openings around protrusions in the insulation system. Weather barrier and

vapor barrier materials are critical components of the insulation system, because they must seal and protect the insulation. Their durability against mechanical abuse, ultraviolet (UV) light degradation, water, and chemicals is of prime importance. In addition, these materials must not contain leachable components that increase the corrosiveness within the insulation system.

In the long term, the weather barriers and vapor barriers break down or are damaged to the point that they can no longer keep the insulation dry. Therefore, maintenance and inspection of weatherproofing are essential to ensure the integrity of the insulation/fireproofing system.

For more information on this subject, refer to Section 5.

2.1.2.3 Effect of Design

Equipment design and mechanical details have an important influence on CUI of carbon steel. Several undesirable design features that influence CUI include:

- (a) Shapes that naturally retain water, such as flat horizontal surfaces, vacuum rings, and insulation support rings;
- (b) Shapes that are difficult or impractical to weatherproof properly, such as gussets, I-beams, and other structural components;
- (c) Shapes that funnel water into the insulation, such as angle-iron brackets;
- (d) Other items that cause interruption in the weatherproofing, such as ladder brackets, nozzle extensions, decking, and platform and pipe supports; and
- (e) Protrusions through insulation on cold service equipment where temperature gradients from cold to ambient occur.

The more breaks there are in the equipment surface, the more likely that water will enter or bypass insulation and drain poorly from equipment. Therefore, high-quality, immersion-grade protective coatings must be used to protect steel and should be included in the design specifications.

For more detailed information on this subject, refer to Section 3.

2.2 Austenitic and Duplex Stainless Steel

The stainless steel alloys most susceptible to SCC are generally classified as the 18-8 stainless steels: austenitic alloys containing approximately 18% chromium, 8% nickel, and the balance iron. In addition to the basic alloy UNS⁽³⁾ S30400, these stainless steel alloys include (among others) the molybdenum-containing grades (e.g., UNS S31600 and S31700), the low-carbon grades (e.g., UNS S30403 and S31603), and the chemically stabilized grades (e.g., UNS S32100 and S34700).

The higher-nickel, chromium, and molybdenum-containing austenitic stainless steel alloys and the lower-nickel, higher-chromium duplex stainless steel alloys have been found to be more resistant to SCC under thermal insulation, but are not immune. For example, recent offshore experience found that under severe conditions, duplex stainless steels also can suffer from external SCC under insulation.⁶ Protective coatings and systems may be used to mitigate the threat associated with CUI of austenitic and duplex stainless steels.

⁽³⁾ Unified Numbering System for Metals and Alloys (UNS). UNS numbers are listed in *Metals & Alloys in the Unified Numbering System* (latest revision). (Warrendale, PA: SAE International and West Conshohocken, PA: ASTM International).

2.2.1 External Stress Corrosion Cracking (ESCC)

2.2.1.1 Mechanism of ESCC

ESCC occurs in austenitic and duplex stainless steel equipment when chlorides or other halides in the environment or insulation material are transported in the presence of water to the hot surface of stainless steel, and are then concentrated by evaporation of that water. This most commonly occurs beneath thermal insulation, but the presence of insulation is not a requirement. Thermal insulation primarily provides a medium to hold and transport the water with its chlorides to the metal surface.

2.2.1.2 Tests and Standards Related to ESCC

Many of the early experiences of ESCC under insulation occurred under wicking insulation. Tests showed that if this wicking insulation contained leachable chlorides, water permeating the insulation could extract chlorides and transport them to the stainless steel surface, which could cause ESCC.

Out of these experiences came ASTM C692 in 1971, as discussed in Paragraph 1.3. That standard was followed in 1977 by ASTM C871⁷ and the final ASTM standard in the series, ASTM C795,⁸ issued in 1992.

These three standards are notable because they established the concepts that:

- (a) Wet insulation containing chlorides causes ESCC; and
- (b) Application of silicate to inhibit chloride in the insulation would be effective in preventing ESCC.

It is now understood that these concepts, although correct, are too limited and not always effective. ESCC failures have been reported under nonwicking insulation. In cases of nonwicking insulation, the water is under the insulation, having entered around it. The chlorides dissolved in the water are from the external sources or the atmosphere, not the insulation materials.

When external water and chlorides enter around an inhibited, wicking insulation material, ESCC can develop because of lack of silicate available on the wetted stainless steel surface. Plant experience shows that the inhibitor is not always leached out of the insulation in sufficient quantities, nor is the inhibitor always in the right place to inhibit the concentrated external chlorides. Sometimes the inhibitor may be leached so thoroughly under severely wetted conditions that it may be transported away from the surfaces needing inhibition.

The wicking test specified in the original publication of ASTM C692 has been modified and the latest revision includes the drip test.⁹ The drip test may be used to evaluate the SCC potential of all types of insulation, wicking and nonwicking, as well as mastics and sealants.

One additional specification related to this matter is ASTM C929,¹⁰ which deals with the handling of certain insulating materials.

In summary, ASTM C692, ASTM C795, ASTM C871, and ASTM C929, as applicable, cover the selection and evaluation of insulation materials with regard to their propensity to cause ESCC of austenitic and duplex stainless steels.

These standards do not address the other aspects of the ESCC problem. If a non-crack-producing insulation is placed in service in a chloride environment, an SCC failure becomes a possibility. Thus, relying solely on materials tested and approved in accordance with ASTM standards may put austenitic and duplex stainless steel equipment in jeopardy. This limitation has not been understood among the engineering, construction, and user groups in the petrochemical and refining industries, among others.

2.2.1.3 Sources, Levels, and Forms of Chlorides

When the ESCC mechanism was first identified, many believed the primary source of chlorides was the insulation itself. Although some insulations do contain appreciable chloride levels, testing and plant experience have shown that the chlorides more frequently come from coastal atmospheres, nearby chloride-containing chemical process units, wash water and fire protection deluge systems, and process spillage. Chloride concentration need not be high in the water, as the hot metal surface concentrates the chlorides by evaporating to a level sufficient to cause ESCC.

2.2.1.3.1 Sources

Sources of chlorides fall into two categories: insulating materials and external sources. A systems approach has been used successfully to develop strategies to combat both categories.

2.2.1.3.1.1 Insulating materials include insulation, mastics, sealants, adhesives, and cements. Failures after only a few years of operation are typically associated with insulating materials containing high levels of leachable chlorides.

2.2.1.3.1.2 External sources include rain, coastal fog, deicing salt, wash water, fire and deluge system testing, and process leaks or spills. Failures caused by introducing chlorides from external sources tend to occur after five years or more of service. These sources account for most of the chloride-induced failures.

2.2.1.3.2 Levels

Experience has shown that insulating materials with as little as 350 ppm chloride have been identified near ESCC locations. Deposits near ESCC events have been found with as little as 1,000 ppm chloride. These levels should be considered when acceptable chloride levels for insulating materials are determined.

2.2.1.3.3 Forms

Sodium chloride is the most prevalent chloride salt found in CUI events. When found in sufficient quantities, it may cause SCC of austenitic and duplex stainless steel. Other sources of chloride ions known to be aggressive include chlorine, hydrogen chloride gas, hydrochloric acid, hydrolyzed organic chlorides, and thermally decomposed (at temperatures as low as 45 °C [115 °F]) polyvinyl chloride (PVC). Likewise, acidic conditions in combination with chloride are more aggressive than neutral or basic conditions. These observations should be considered when insulating materials are specified.

2.2.1.4 Effect of Temperature

Temperature has a twofold effect. First, as stated above, at elevated temperature water evaporates as it contacts the hot stainless steel surface. This evaporation can concentrate the chloride salts, allowing them to be deposited on the metal surface. Second, as temperature increases, the rate of the corrosion reaction increases, and the time decreases for initiation and propagation of ESCC.

Most ESCC failures occur when metal skin temperature is in the “hot water” range: 50 to 175 °C (120 to 350 °F). Failures are less frequent when metal skin temperature is outside this range.

Below 50 °C (120 °F), the reaction rate is low and the evaporative concentration mechanism is not significant. Above 175 °C (350 °F), water is not normally present on the metal surface, and failures are infrequent. Equipment that cycles through the water dew point is particularly susceptible. Water present at the low temperature evaporates at the higher temperature. During each temperature cycle, the chloride salts dissolved in the water concentrate on the surface.

2.2.1.5 Role of Stress

For ESCC to develop, sufficient tensile stress must be present in the stainless steel. If the tensile stress is eliminated or sufficiently reduced, the cracking does not occur. The threshold stress required to develop cracking depends somewhat on the cracking medium. Most mill products, such as sheet, plate, pipe, and tubing, contain sufficient residual tensile stresses after processing to develop cracks without applied stresses. When 18-8 stainless steels are cold formed and welded, additional residual stresses are imposed. As the total stress rises, the potential for ESCC increases. Attempts to control ESCC by reducing the tensile stress by thermal treatment are not practical.

2.2.2 Effects of Types of Insulation

The solution to ESCC of stainless steel does not lie with the type of insulation chosen. Industry experience and testing have shown that ESCC occurs under all types of insulation materials. Insulations that absorb water are particularly troublesome in that they hold water and slowly allow the concentration mechanism to proceed. Insulations that do not absorb water are frequently specified in an attempt to lessen the problem, but without other preventive measures, cracking may still occur.

Polyurethane foam, polyisocyanurate foam, and phenolic foam do not provide immunity to ESCC, especially when used in the hot water range. Residual chlorine or bromine compounds used in manufacturing the foam may leach out and hydrolyze, forming an acidic condition that accelerates the cracking of austenitic and duplex stainless steels.

For more detailed information on insulation materials, refer to Section 5.

2.2.3 Effects of Mastics and Sealants

If water could be excluded, the insulation would stay dry, and ESCC would not occur. Although this sounds like a reasonable approach toward prevention, in practice it is extremely difficult to prevent water ingress. In fact, once insulation becomes wetted, the weather barriers, mastics, and sealants make water escape difficult, so the insulation remains wet. Also, mastics and sealants may contain water-leachable chlorides that can contribute to ESCC problems.

For more information on mastics and sealants, refer to Section 5.

2.2.4 Effect of Design

As with carbon steel, equipment design and mechanical details have an important influence on CUI of stainless steel. Several undesirable design features that influence CUI include:

- (a) Shapes that naturally retain water, such as flat horizontal surfaces, vacuum rings, and insulation support rings;
- (b) Shapes that are difficult or impractical to weatherproof properly, such as gussets, I-beams, and other structural components;
- (c) Shapes that funnel water into the insulation, such as angle-iron brackets;
- (d) Other items that cause interruption in the weatherproofing, such as ladder brackets, nozzle extensions, decking, and platform and pipe supports; and
- (e) Protrusions through insulation on cold service equipment where temperature gradients from cold to ambient occur.

Design steps to minimize water ingress are beneficial but not normally adequate to prevent ESCC. Some amount of water entry into the insulation system eventually occurs. High-quality immersion-grade protective coatings or aluminum foil, as outlined later in this standard, may be specified to protect austenitic and duplex stainless steels.

For more information on design, see Section 3, and for protective coatings, see Section 4.

Section 3: Mechanical Design

- 3.1** Poorly designed or applied insulation systems and protrusions through thermal insulation permit water to bypass the insulation, thereby corroding the substrate metal.¹⁰ Metal also corrodes when weather barriers and vapor barriers break down after equipment is put in service and exposed to the weather. This often results in structural failures, unplanned or extended shutdowns, and unscheduled replacement of equipment. Insulation system life can be prolonged and substrate metal corrosion can be reduced by better design of protrusions, attachments, and supports associated with equipment.

3.2 Thermal Insulation System Design

Equipment is insulated for any of the following reasons:

- (a) Heat conservation and/or freeze protection;
- (b) Process control;
- (c) Personnel protection;
- (d) Sound control;
- (e) Condensation control; and
- (f) Fire protection.

Insulated surfaces for carbon steel operating continuously above 175 °C (350 °F) or below -4 °C (25 °F) and for austenitic and duplex stainless steel operating continuously above 175 °C (350 °F) or below 50 °C (120 °F) do not present major corrosion problems. However, equipment operating either steadily or cyclically between these temperatures may suffer significant corrosion problems. These problems are aggravated by selecting inadequate insulation materials and by improper insulation design. Guidelines for proper design to control corrosion in thermal insulation systems are presented below.

3.2.1 Specification Requirements

Insulation specifications are critical requirements for insulation system design and installation work. They control material and application requirements. Loosely written specifications with insufficient material descriptions and application requirements may result in costly repairs during construction or after the plant is operational.

Common specification flaws to be avoided are:

- (a) Incorrect application of materials, e.g., open-cell or wicking-type insulation materials, such as calcium silicate and fibrous products, specified for below-ambient temperature applications;
- (b) Product specification by using a generic name without stating the properties required for the intended service; and
- (c) Improper and unclear application methods, e.g., incorrect multilayer schedules, lack of expansion joints, missing vapor barriers, and incorrect insulation securing methods.

A specification needs to be complete and detailed. It must clearly describe materials, application, and finishing requirements. If a service needs special attention from an insulation standpoint, it should be stated in the specification.

For more information on insulation materials, see Section 5.

3.3 Effect of Equipment Attachment Design

The design of equipment attachments is an important part of insulation system design. The shape, geometry, and orientation of attachments can allow moisture or rainwater to bypass the insulation and concentrate at the attachment point. Examples of such attachments are shown in Figures 2 and 3. Attention to details such as these is important to produce a high-quality insulation system.

Some attachment shapes can be modified to be easier to seal, but this is not always possible. Although structural steel angles are among the most difficult shapes to weatherproof, they are widely used in industry. Sometimes pressure vessel codes dictate which attachment shapes may be used. Caulking compounds used at jacketing penetrations keep rain water out only until the com-

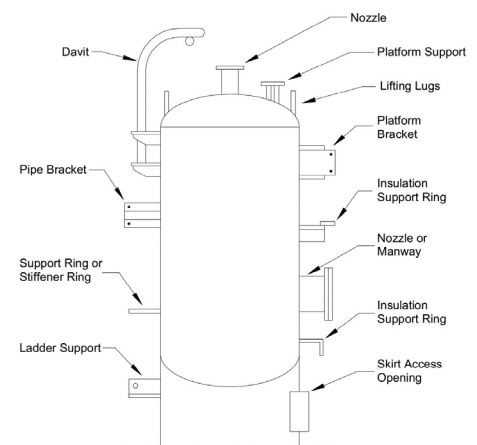


Figure 2: Typical Vessel Attachments Where Water May Bypass Insulation

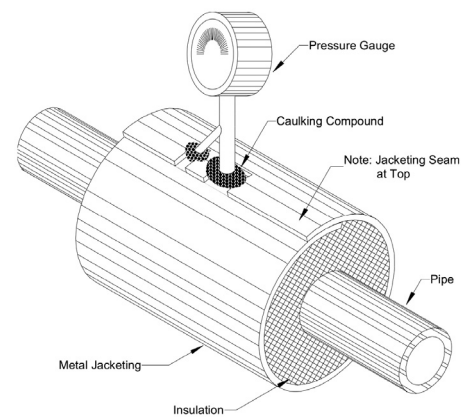
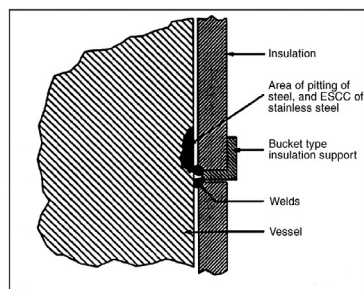
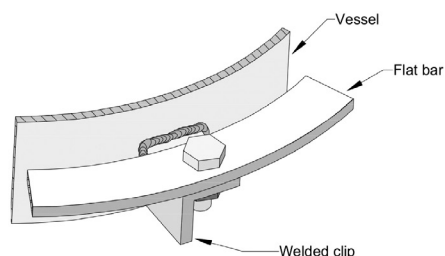


Figure 3: Attachment to Piping Where Water May Bypass Insulation. Attachment Relies on Caulking Compound Only.



(a) Corrosion Problems with Bucket-Type Insulation Support Ring



(b) Flat Bar-Type Support Ring Eliminates Moisture Accumulation

Figure 4: Vessel Insulation Support Ring—the Problem (a) and the Solution (b)

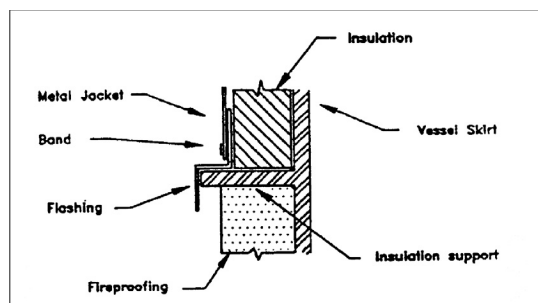


Figure 5: Vertical Vessel Bottom Support Ring Minimizing Water Accumulation

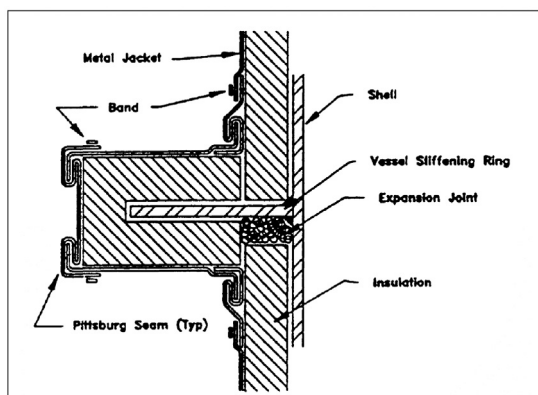


Figure 6: Vessel-Stiffening Ring Insulation Detail. Seams prevent water intrusion.

pounds fail because of weathering or burn off because of high equipment operating temperatures. Therefore, insulation designs relying only on these compounds may fail prematurely.

Several problems are frequently encountered when insulating vessels and piping:

3.3.1 Problems Insulating Vessels and Similar Equipment

3.3.1.1 The lip or rim on bucket-type insulation support rings on vessels may act as a moisture dam, leading to severe corrosion and pitting of the vessel. A relatively inexpensive alternative design—a flat bar bolted onto welded clips, which is shown in Figure 4—can minimize moisture accumulation.

3.3.1.2 Vertical vessel bottom support rings can accumulate moisture at the metal-to-insulation interface if the interface is unprotected. The design principle shown in Figure 4 is extended to this application in Figure 5. An economical flat cut bar can be used. The flashing ring, which can be field fabricated, protects the insulation and fireproofing by deflecting water over and down the support ring edge.

3.3.1.3 Stiffening rings extending beyond the insulation may allow moisture intrusion. Built-up insulation and jacketing with “Pittsburgh seams” and proper overlaps, as shown in Figure 6, can prevent the intrusion.

3.3.1.4 Uninsulated nozzles located on the top heads of vertical vessels can divert water under insulation. The caulking compound and metal flashing normally used in this situation do very little to keep out the water. This problem can be remedied by extending the nozzle beyond the insulation and jacketing as shown in Figure 7, and then by insulating the nozzle up to the cap. The cap depends on a seal weld around the nozzle, not on sealants, to prevent water passage past the insulation.

3.3.1.5 The bracket supporting the nameplate on a vessel can permit water intrusion past the insulation where the bracket penetrates it. This is illustrated in Figure 8. A shorter bracket that does not extend beyond the insulation may be used for permanent identification of the vessel, and a duplicate nameplate may be mounted on the outside of the metal jacketing or bottom skirt for in-service identification.

3.3.2 Problems Insulating Piping

3.3.2.1 Insulation of piping for personnel protection can incur water entry at the termination if it is unsealed. Seal-welding a cap, as demonstrated in Figure 9, can prevent water entry. An alternative is to forego the insulation and use expanded metal on stand-offs.

3.3.2.2 Using angle iron or C-channel to support double pipe heat exchangers creates many protrusions through the insulation. See Figure 10 as an illustration. These protrusions are difficult to seal and afford entry points for moisture. Using a tubular support provides a surface and protrusion-to-insulation contour that is easier to seal.

3.3.2.3 Rod hangers or clamps supporting piping by direct contact make protrusions through the jacketing as shown in Figure 11. Water can enter past the insulation when the caulking compound dries enough to crack or to separate from the insulation. However, load-bearing sup-

ports that contact only the jacketing, as shown in Figure 12, allow a continuous weather barrier.

3.3.2.4 When insulated piping rests directly on structural beams, the weather barrier must be cut around the steel. This breaks the weather barrier continuity and allows moisture intrusion. However, piping supported as shown in Figure 12 keeps the weather barrier continuous. The insulation and jacketing are free to move with the piping, and water intrusion is reduced.

3.3.2.5 The vapor barrier of insulated piping in cold service is not continuous when the piping is supported as shown in Figure 13. Instead, the integrity of the insulation system relies on joint sealants and caulking compounds used at the insulation-to-pipe support interface. These compounds cannot maintain their seal when the piping moves, and moisture may intrude. Figure 14 shows the design of a piping support fabricated with a built-in vapor barrier that remains continuous despite piping movement.

3.3.2.6 In cold service, insulation and vapor barriers are often penetrated for improved access to equipment lying close to the insulation, such as instrument connections, drain-valve hand wheels, and valve packing glands. These penetrations can allow moisture intrusion and condensation. The problem is avoided by extending valve stems and instrument connections above the insulation.

3.3.2.7 Clearance for insulation between piping and adjacent structures can be insufficient because of incorrect pipe spacing, unexpected thickness of steel column fireproofing, and unexpected piping movement. This inadequate clearance often permits moisture to bypass weatherproofing and vaporproofing, as shown in Figure 15. The only cure is to design adequate space for insulation. Design considerations should include effects of adjacent structures, piping movement, and expansion joints.

3.3.2.8 Electrical conduit suspended from piping or penetrating its insulation presents insulation sealing difficulties for both hot and cold service. Moreover, in extremely hot service, the conduit may suffer overheating damage; in cold service, the conduit may corrode. The remedy is to avoid penetrating piping insulation, e.g., suspend conduit from structural members.

3.3.2.9 Providing adequate piping clearances, attending to attachment geometry, and understanding incidental corrosion may preclude many of the problems described above. Knowledge of various insulation materials and their installation requirements, along with knowledge of equipment, is necessary for corrosion control.

3.4 Weather Barrier and Vapor Barrier Design

In insulation system design, selection of weather barriers and vapor barriers is as important as selection of thermal insulation. Although it is easy to say “keep water out,” in practice, keeping water out is not always feasible. Weather barriers and vapor barriers break down because of chemical attack, sunlight, mechanical damage, and galvanic corrosion. Caulking compounds and mastics used during construction for sealing jacket seams degrade in sunlight and at temperatures exceeding the materials’ recommended use limits. Vapor barriers also degrade in sunlight, creating cracks and open seams that allow moisture penetration.

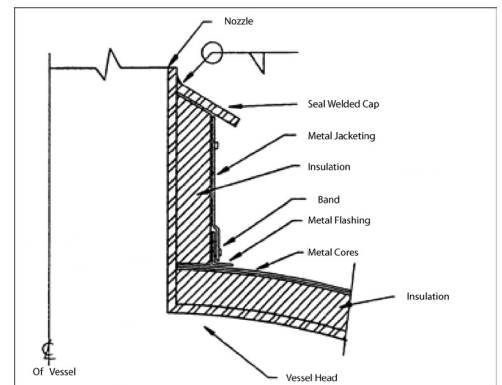


Figure 7: Center Nozzle at Top Head of Vessel. Extended and insulated with seal-welded cap.

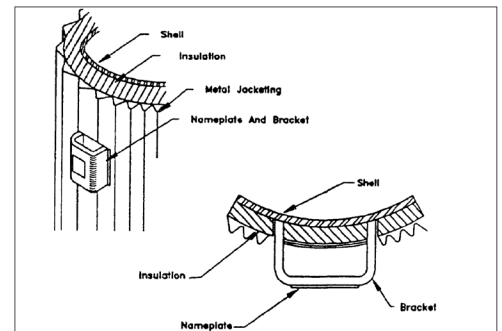


Figure 8: Common Nameplate Insulation Detail. Water may enter through bracket penetration.

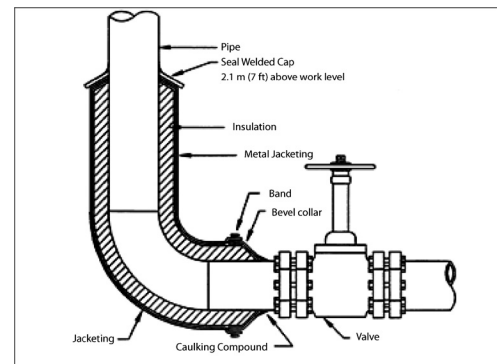


Figure 9: Seal-Welded Cap on Insulation for Personnel Protection. Cap prevents water entry.

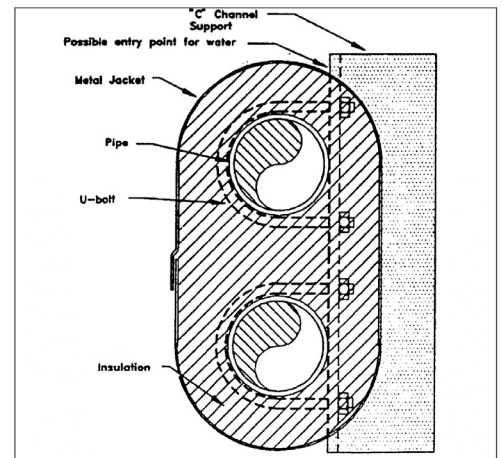


Figure 10: Double-Pipe Heat Exchanger Insulation Penetrated by C-Channel Support. Water entry points shown.

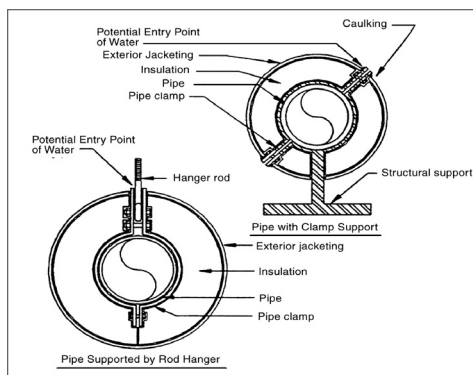


Figure 11: Protrusions Through Jacketing

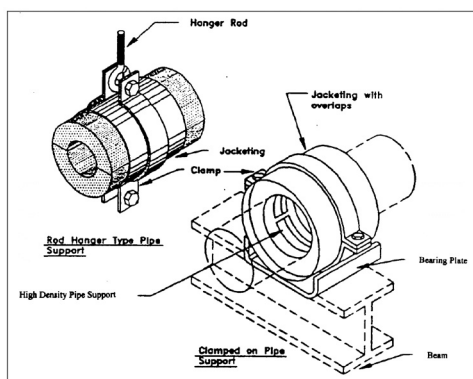


Figure 12: Pipe Supports Without Protrusions

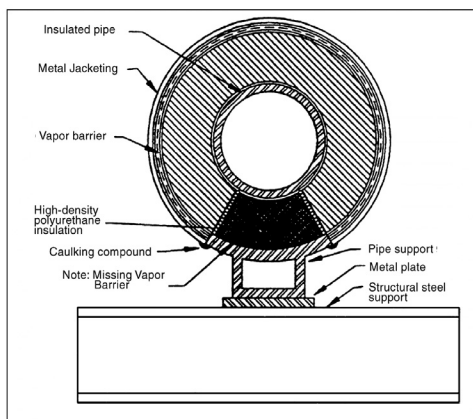


Figure 13: Cold Service Pipe Support Without Continuous Vapor Barrier

In cold service, thermal insulation relies on a vapor barrier to keep out moisture. With the possible exception of an all-welded metal sleeve enclosure, there is no perfect vapor barrier. Mastic vapor barriers without metal jacketing require periodic inspections to check for signs of mechanical damage, aging, cracking, delaminations, and broken seals. Unattended repairs shorten insulation life and promote corrosion. Metal jackets over vapor barriers on cold service insulation should be avoided unless needed for protection of the insulation.

In warm service, weather barriers are normally metallic. They are fabricated from roll jacketing and can have many seams. Sometimes seams are installed on top surfaces or have improper overlaps. Overlap seams are more vulnerable to foot traffic damage when thin metallic jacketing is used over fibrous insulation.

The use of dissimilar metals in metallic jacket design in the presence of moisture should be avoided, as this often causes galvanic corrosion.

3.5 Insulation System Design

Insulation designs for rigid and semirigid materials may require expansion joints, depending on operating temperatures and sizes of equipment. Failure to use these joints at the required locations in the insulation may lead to its uncontrolled movement. As a result, weather barriers and vapor barriers break down. This can allow migration of water into the insulation and lead to corrosion. Normally, insulation design for flexible materials, such as fibrous blanket, does not require expansion joints.

System designers may fail to allow for movement of insulation caused by piping expansion. For example, based on the coefficients of thermal expansion at -73°C (-100°F) and 20°C (68°F), cellular glass insulation expands about the same amount as carbon steel, whereas cellular foam expands about nine times more than carbon steel. When the insulated system cools, joints compress in cellular glass but open in cellular foam. Therefore, cellular foams (such as a polyurethane system) require more expansion joints. Also, to control the lateral migration of water vapor, polyurethane insulated systems need more frequent vapor stops than do cellular glass systems.

Section 4: Protective Coatings

4.1 Scope

4.1.1 This section presents information for the selection of protective coatings for carbon steel and austenitic and duplex stainless steels under thermal and/or noise reduction insulation systems and fireproofing. Protective coatings have been recognized and accepted and should be used as a highly effective method of protecting insulated carbon steel and austenitic and duplex stainless steel from corrosion. Attempts to prevent water from entering insulated systems are not sufficiently reliable to prevent CUI, and corrosion protection techniques such as inhibitors and cathodic protection have been less effective than protective coatings in mitigating corrosion under insulation.

4.1.2 Coating systems considered in this section are thin-film liquid-applied coatings, fusion-bonded coatings, metallizing (thermal spray), and wax-tape coatings. These systems have a history of successful use. Other systems may also be satisfactory.

4.1.3 Insulation covering (lagging) is not addressed in this section. See Section 5.

4.1.4 Coating manufacturers or project specifications should be consulted regarding the suitability of specific products for carbon steels, austenitic stainless steels, and duplex stainless steels under insulation systems. Potentially deleterious interactions between leachable materials from the insulation may affect the coating systems.

4.2 Coating Austenitic and Duplex Stainless Steels Under Thermal Insulation

4.2.1 Austenitic and duplex stainless steels can be subject to ESCC when covered with insulation. Also, if a metal-containing coating is heated beyond the metal's melting point, liquid metal cracking (LMC) of austenitic and duplex stainless steels may occur. Consequently, the criteria for a coating system used to prevent ESCC and LMC of austenitic and duplex stainless steels are as follows:

4.2.1.1 The coating system shall not contain free, soluble chlorides or other halides after curing beyond those levels established by ASTM C795 and ASTM C871. Chlorides are present in normal environments and, over time, usually exceed the amount contributed by coating systems. Compounds of chlorides or other halides within the cured-resin chemical molecule are not considered harmful unless they are subject to release through aging within the expected service temperature range.

4.2.1.2 Because of the potential for LMC, the coating shall not contain metallic zinc in its formulation.

4.2.1.3 The coating shall be selected for the expected service temperature range if this range could allow moisture to occur on substrate surfaces. This is especially true with processes using intermittent thermal cycling through the dew point.

4.2.2 Table 1 lists typical protective coating systems for austenitic and duplex stainless steel equipment. Maximum and minimum service temperatures and their duration in the proposed application should be considered in selecting a coating system. For other coating systems, the manufacturer should be consulted regarding expected coating system performance.

4.2.3 Aluminum foil wrapping may be used to prevent ESCC of austenitic and duplex stainless steels under insulation.

4.3 Coating Carbon Steel Under Thermal Insulation and Fireproofing

4.3.1 The coating systems recommended for use on carbon steel operating below 175 °C (350 °F) under thermal insulation are typically tank lining systems formulated to prevent corrosion. Other coatings may be used at the buyer's discretion.

4.3.2 Epoxy protective coatings, as a class of materials, should be used on carbon steel under fireproofing.

4.3.3 If galvanized steel under fireproofing has been corroding, coating the galvanized steel should be considered. The manufacturer of proprietary fireproofing should be consulted regarding the compatibility of the fireproofing with galvanized steel.

4.3.4 Users who purge piping with steam shall select a coating system capable of withstanding the surface temperature for the duration of the purging. The coating manufacturer should be consulted for specific temperature resistance information.

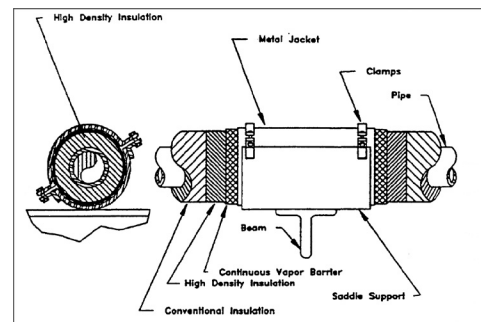


Figure 14: Cold Service Pipe Support with Continuous Vapor Barrier

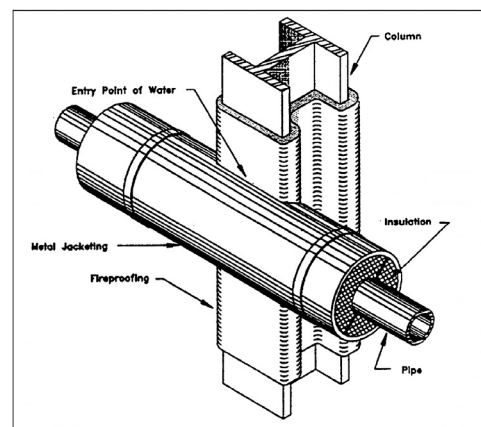


Figure 15: Pipe Insulation Penetrated by Column Fireproofing

Table 1
Typical Protective Coating Systems for Austenitic and Duplex Stainless Steels Under Thermal Insulation

System Number	Temperature Range^{(A) (B)}	Surface Preparation^(C)	Surface Profile, μm (mil)^(D)	Prime Coat, μm (mil)^(E)	Finish Coat, μm (mil)^(E)
SS-1	–45 to 60 °C (–50 to 140 °F)	SSPC1 ⁽⁴⁾ –SP 1 ¹¹ and abrasive blast	50–75 (2–3)	High-build epoxy, 125–175 (5–7)	N/A
SS-2	–45 to 150 °C (–50 to 300 °F)	SSPC-SP 1 and abrasive blast	50–75 (2–3)	Epoxy phenolic, 100–150 (4–6)	Epoxy phenolic, 100–150 (4–6)
SS-3	–45 to 205 °C (–50 to 400 °F)	SSPC-SP 1 and abrasive blast	50–75 (2–3)	Epoxy novolac, 100–200 (4–8)	Epoxy novolac, 100–200 (4–8)
SS-4	–45 to 540 °C (–50 to 1,000 °F)	SSPC-SP 1 and abrasive blast	15–25 (0.5–1.0)	Air-dried silicone or modified silicone, 37–50 (1.5–2.0)	Air-dried silicone or modified silicone, 37–50 (1.5–2.0)
SS-5	–45 to 650 °C (–50 to 1,200 °F)	SSPC-SP 1 and abrasive blast	40–65 (1.5–2.5)	Inorganic copolymer or coatings with an inert multipolymeric matrix, ^(F) 100–150 (4–6)	Inorganic copolymer or coatings with an inert multipolymeric matrix, ^(F) 100–150 (4–6)
SS-6	–45 to 595 °C (–50 to 1,100 °F)	SSPC-SP 1 and abrasive blast	50–100 (2–4)	Thermal-sprayed aluminum (TSA) with minimum of 99% aluminum, 250–375 (10–15)	Optional: sealer with either thinned epoxy-based or silicone coating (depending on max. service temperature) at approximately 40 (1.5)
SS-7	–45 to 540 °C (–50 to 1,000 °F)	SSPC-SP 1	N/A	Aluminum foil wrap with min. thickness of 64 (2.5)	N/A

^(A) The temperature range shown for a coating system is that over which the coating system is designed to maintain its integrity and capability to perform as specified when correctly applied. However, the owner may determine whether any coating system is required, based on corrosion resistance of austenitic and duplex stainless steels at certain temperatures. Temperature ranges are typical for the coating system; however, specifications and coating manufacturer's recommendations should be followed. SS-4, SS-5, SS-6, and SS-7 may be used under frequent thermal cyclic conditions in accordance with manufacturer's recommendations.

^(B) Temperature range refers to the allowable temperature capabilities of the coating system, not service temperatures. An experienced metallurgist should be consulted before exposing duplex stainless steel to temperatures greater than 300 °C (572 °F).

^(C) To avoid surface contamination, austenitic and duplex stainless steels shall be blasted with nonmetallic grit such as silicon carbide, garnet, or virgin aluminum oxide. Because there are no specifications for the degree of cleanliness of abrasive blasted austenitic and duplex stainless steels, the owner should state the degree of cleanliness required after abrasive blasting, if applicable, and whether existing coatings are to be totally removed or whether tightly adhering coatings are acceptable.

^(D) Typical minimum and maximum surface profile is given for each substrate. Acceptable surface profile range may vary, depending on substrate and type of coating. Coating manufacturer's recommendations should be followed.

^(E) Coating thicknesses are typical dry film thickness (DFT) values, but the user should always check the manufacturer's product data sheet for recommended coating thicknesses.

^(F) Consult with the coating manufacturer for actual temperature limits of these coatings.

⁽⁴⁾ SSPC: The Society for Protective Coatings (SSPC), 800 Trumbull Dr., Pittsburgh, PA 15205.

Table 2
Typical Protective Coating Systems for Carbon Steels Under Thermal Insulation and Fireproofing

System Number	Temperature Range ^(A) ^(B)	Surface Preparation	Surface Profile, μm (mil) ^(C)	Prime Coat, μm (mil) ^(D)	Finish Coat, μm (mil) ^(D)
CS-1	–45 to 60 °C (–50 to 140 °F)	NACE No. 2/ SSPC-SP 10 ¹⁴	50–75 (2–3)	High-build epoxy, 130 (5)	Epoxy, 130 (5)
CS-2 (shop application only)	–45 to 60 °C (–50 to 140 °F)	NACE No. 2/ SSPC-SP 10	50–75 (2–3)	N/A	Fusion-bonded epoxy (FBE), 300 (12)
CS-3	–45 to 150 °C (–50 to 300 °F)	NACE No. 2/ SSPC- SP 10	50–75 (2–3)	Epoxy phenolic, 100–150 (4–6)	Epoxy phenolic, 100–150 (4–6)
CS-4	–45 to 205 °C (–50 to 400 °F)	NACE No. 2/ SSPC- SP 10	50–75 (2–3)	Epoxy novolac or silicone hybrid, 100–200 (4–8)	Epoxy novolac or silicone hybrid, 100–200 (4–8)
CS-5	–45 to 595 °C (–50 to 1,100 °F)	NACE No. 1/ SSPC-SP 5 ¹⁵	50–100 (2–4)	TSA, 250–375 (10–15) with minimum of 99% aluminum	Optional: Sealer with either a thinned epoxy-based or silicone coating (depending on maximum service temperature) at approximately 40 (1.5) thickness.
CS-6	–45 to 650 °C (–50 to 1,200 °F)	NACE No. 2/ SSPC-SP 10	40–65 (1.5–2.5)	Inorganic copolymer or coatings with an inert multipolymeric matrix, 100–150 (4–6)	Inorganic copolymer or coatings with an inert multipolymeric matrix, 100–150 (4–6)
CS-7	60 °C (140 °F) maximum	SSPC-SP 2 ¹⁶ or SSPC-SP 3 ¹⁷	N/A	Thin film of petrolatum or petroleum wax primer	Petrolatum or petroleum wax tape, 1–2 (40–80)
CS-8 Bulk or shop-primed pipe, coated with inorganic zinc	–45 to 400 °C (–50 to 750 °F)	Low-pressure water cleaning to 3,000 psi (20 MPa) if necessary	N/A	N/A	Epoxy novolac, epoxy phenolic, silicone, modified silicone, inorganic copolymer, or a coating with an inert multipolymeric matrix, is typically applied in the field. Consult coating manufacturer for thickness and service temperature limits. ^(E)
CS-9 Carbon steel under fireproofing	Ambient	NACE No. 2/ SSPC-SP 10	50–75 (2–3)	Epoxy or epoxy phenolic, 100–150 (4–6)	Epoxy or epoxy phenolic, 100–150 (4–6)
CS-10 Galvanized steel under fireproofing	Ambient	Galvanizing: sweep blast with fine, nonmetallic grit	25 (1)	Epoxy or epoxy phenolic (for more information on coatings over galvanizing, see 4.3.3), 100–150 (4–6)	Epoxy or epoxy phenolic, 100–150 (4–6)

^(A) The temperature range shown for a coating system (including thermal-cycling within this range) is that over which the coating system is designed to maintain its integrity and capability to perform as specified when correctly applied. However, the owner may determine whether any coating system is required, based on corrosion resistance of carbon steel at certain temperatures. Temperature ranges are typical for the coating system; however, not all coatings in a category are rated for the given minimum/maximum temperature. Specifications and coating manufacturer's recommendations should be followed for a particular coating system.

^(B) Temperature range refers to the allowable temperature capabilities of the coating system, not service temperatures.

^(C) Typical minimum and maximum surface profile is given for each substrate. Acceptable surface profile range may vary, depending on substrate and type of coating. The coating manufacturer's recommendations should be followed.

^(D) Coating thicknesses are typical DFT values, but the user should always check the manufacturer's product data sheet for recommended coating thicknesses.

^(E) If inorganic zinc-rich coating is applied in a shop and topcoat is applied in the field, proper cleaning of the inorganic zinc-rich coating is required. The use of inorganic zinc-rich coating under insulation is not a preferred system for service temperatures in the CUI range up to approximately 175 °C (350 °F). However, bulk piping is often coated with inorganic zinc-rich coating in the shop and some owners purchase this piping for use under insulation. In these cases, the inorganic zinc-rich coating should be topcoated to extend its life.

4.3.5 Inorganic zinc-rich coating shall not be used by itself under thermal insulation in the 50 to 175 °C (120 to 350 °F) service temperature range for long-term or cyclic service. Zinc provides inadequate corrosion resistance in closed, sometimes wet, environments. At elevated temperatures greater than approximately 60 °C, the zinc may undergo a galvanic reversal whereby the zinc becomes cathodic to the carbon steel.

4.3.6 Thermal-sprayed aluminum (TSA) coatings have performed successfully in marine and high-temperature environments.¹²

4.3.7 Wax-tape coatings may be used to prevent corrosion of carbon steel during a dry cycle or when cycling through the dew point. Tape application procedures should follow those prescribed in NACE Standard RP0375¹³ for wax-tape coating systems.

4.3.8 Table 2 lists protective coating systems typically used for carbon steel equipment. The user should select the coating system appropriate for the expected temperature range. Maximum and minimum service temperatures and their duration in the proposed application should be considered in selecting a coating system. For other coating systems, the manufacturer should be consulted regarding expected coating system performance.

Section 5: Insulation, Fireproofing, and Accessory Materials

5.1 Scope

This section describes the properties of industrial insulation, insulation accessories, and fireproofing materials that affect corrosion. Other performance properties of these materials are not characterized. Emphasis is placed on service performance characteristics, exposure to operating temperatures, and the ability to exclude water over the design life of the system.

5.2 Insulation Materials

Commonly used industrial insulation materials are described and grouped generically. No attempt is made to describe every commercial product available on the market. Differences between specific commercial products within a generic type are not addressed.

Insulation materials for use on austenitic stainless steels, as appropriate, should be qualified in accordance with ASTM C795. Some users specify a maximum chloride content in addition to those measurements given in ASTM C795, such as 100 ppm for perlite, 200 ppm for calcium silicate, and 25 ppm for mineral man-made fiber insulation. Also, some users specify the ratio of sodium silicate to chlorides as 20 to 1 for calcium silicate and mineral fiber or 200 to 1 for perlite. At present, there are no similar tests or guidelines for qualifying insulation materials in contact with duplex stainless steels.

Using references in ASTM C795, ASTM C692 specifies the test methods for qualifying insulation materials. The drip method provides a technique that closely simulates insulated systems. Modifications of this method and apparatus may be useful in the testing of coatings in combination with insulation materials over a temperature-controlled substrate.

ASTM standard material specifications refer to various test methods for use in characterizing insulation materials and accessories. Manufacturers should be encouraged to provide test information, preferably performed by an independent third party. This information may be very useful in characterizing specific commercial materials.

5.2.1 Calcium Silicate

Calcium silicate pipe and block insulation is specified in ASTM C533.¹⁸ It is a rigid pipe and block insulation composed principally of hydrous calcium silicate and usually incorporates a fibrous reinforcement.

Calcium silicate is intended as a high-temperature insulation. At ambient temperatures, it can absorb up to 400% of its weight when immersed in water. It is hygroscopic and absorbs 20 to 25% by weight water in humid conditions from water vapor present in air. For this reason, most manufacturers publish a lower temperature limit, typically 150 °C (300 °F), for its use outdoors.

Calcium silicate, when wet, is alkaline, having a pH of 9 to 10. High pH may be detrimental to coatings such as alkyds and inorganic zinc.

Most problems with calcium silicate are associated with use at temperatures lower than recommended cyclic temperature services with an ambient temperature for the majority of the time, and with equipment subject to extended shutdown.

5.2.2 Expanded Perlite

Expanded perlite block and pipe insulation is specified in ASTM C610.¹⁹ It is composed of expanded perlite, inorganic silicate binders, fibrous reinforcement, and silicone water-resistant additions. It is a rigid material furnished in block and pipe cover forms. Expanded perlite is used as a moderate-to-high-temperature insulation. At lower temperatures, the additives for water resistance provide protection from absorption of water. At approximately 315 °C (600 °F), some additives burn out, and water resistance is reduced. ASTM C610 includes a test method for determining the effect of temperature on water resistance.

5.2.3 Man-Made Mineral Fibers

ASTM groups commercial glass and mineral fiber insulation materials into a single category, generally described as rocks, slag, or glass processed from a molten state into a fibrous form and including organic binders. Generally, these materials are used from ambient to high temperatures. The upper temperature limits vary, depending on the specific fiber and binder. Typically, mineral fibers have a higher temperature limit. Several ASTM standards address various forms.

Water absorption characteristics of these products vary greatly. Fiber length and orientation affect these characteristics which, in turn, affect wicking, binder composition and quantity, and burn-out characteristics of the binder.

Ability of fibrous insulation to repel water varies from product to product and depends on the type of binder used. Some binders break down in the presence of heat and water. After binder breakdown, these products can become excellent wicking material, transmitting moisture and corrosive solutions to the underlying metal surface. Fibrous products also allow water vapor to permeate. Their use in below-ambient temperature applications, even with a vapor barrier, has had limited success. Construction joints (overlaps and field joints glued together during installation of vapor barrier sheet) or damaged sections of vapor barriers allow moisture to migrate into the insulation system. With time and repeated thermal cycling, these vapor barrier joints fail, allowing the passage of moisture.

Compressive strength varies with density of the material and the effect of binder burn-out. Although change in compressive strength does not directly affect corrosion, materials with low compressive strength result in an insulation system with typical metal jacketing that is vulnerable to physical damage, allowing water intrusion.

5.2.4 Cellular Glass

Cellular glass is specified in ASTM C552.²⁰ It is a rigid block material that has been foamed under molten conditions to form a closed cell structure. It is commonly used in the below-ambient to moderate temperature range (–25 °C to 200 °C [–13 °F to 392 °F]). A common use is as insulation on electric-traced or steam-traced piping for either freeze protection or process control.

Cellular glass is water resistant and retains only small amounts of water on cut or fractured surfaces. However, water entering through cracks or joints in the insulation system can reach the metal surface and cause corrosion and ESCC.

5.2.5 Organic Foams

ASTM standards include specifications for various types and forms of organic foam insulation. The types most commonly used in industrial applications include polyurethane, polyisocyanurate, flexible elastomeric, and phenolic. Polystyrene and polyolefin are less commonly used because of temperature limitations. Organic foams are used in below-ambient to moderate temperature applications and have water vapor ratings from 0.15×10^{-12} to 7.3×10^{-12} kg/Pa · s · m (0.1 to 5 perm · in).

These materials may contain leachable chlorides, fluorides, silicate, and sodium ions as measured in accordance with ASTM C871. The pH, chloride content, fluoride content, silicate content, and sodium content are obtained from the leachate produced by boiling pulverized foam in water. Levels of leachable chlorides may range from nondetectable to 200 ppm. The leachate pH may range from 1.7 to 10.0. When the leachate pH is less than 6.0, special consideration should be given to protect the substrate from accelerated corrosion.

5.2.5.1 Spray-applied polyurethane foam insulation is specified in ASTM C1029.²¹ It is a rigid, closed-cell foam that is formed by a chemical reaction at the time of application.

5.2.5.2 Preformed polyisocyanurate foam insulation is specified in ASTM C591.²² It is a rigid, closed-cell foam that is formed by a controlled chemical reaction.

5.2.5.3 Preformed flexible elastomeric insulation is specified in ASTM C534.²³ It is a flexible, closed-cell foam that is formed by an extrusion process.

5.2.5.4 Faced or unfaced phenolic foam insulation is specified in ASTM C1126.²⁴ It is a rigid, closed-cell foam that is formed by a controlled chemical reaction.

5.2.5.5 Preformed polystyrene foam insulation is specified by ASTM C578.²⁵ It is a rigid, closed-cell foam that is formed by either an extrusion or molding process.

5.2.6 Ceramic Fiber

ASTM specifies ceramic fiber separately from man-made mineral fiber. It is typically used in high-temperature applications. Its use at lower temperatures is limited because of its high cost.

If the fiber is used at moderate temperatures, the wicking characteristics of the particular product form affect water absorption.

5.2.7 Prefabricated Systems

Many products on the market combine insulation materials with various accessories to produce prefabricated systems intended to enhance installation efficiencies and/or overall service performance. All components of a system must be considered for a particular application. Of particular interest are minor components (accessory materials) that may be detrimental to austenitic and duplex stainless steels (see Paragraph 5.3).

5.2.8 Historical Materials

Materials that are no longer manufactured, or are rarely used today, may be of concern in existing systems. In particular, asbestos and magnesium-based materials may contain high levels of chlorides.

5.3 Insulation Accessory Materials

Insulation accessory materials include those components used to fabricate insulation materials into shapes that fit the equipment, as well as components used to apply those shapes, provide weatherproofing, and seal projections through the insulation system.

Materials such as cements, mastics, and coatings may require mixing with water before use. In that case, water quality is a concern. When used over austenitic and duplex stainless steels, maximum chloride content of the water must be specified. Concentrations should be less than 100 ppm. The best practice is to use condensate or some other high-purity water source.

Some users specify mastics and sealants that do not contain PVC, brominated compounds, chlorinated hydrocarbons, or acetic acid derivatives because the compounds promote ESCC.

ASTM standard test methods for insulation materials used over austenitic and duplex stainless steels are not always appropriate for accessory materials. Some specifiers refer to Nuclear Regulatory Commission⁽⁶⁾ requirements.

5.3.1 Cements

Cements are used to join insulation materials into useful shapes. Hydrated silicates are used with calcium silicate, perlite, and cellular glass. Water quality is a concern. Asphaltic materials are commonly used in low-temperature systems. Some asphaltic materials may not pass acceptance testing for use with austenitic and duplex stainless steels. Materials containing chlorinated polymers, such as PVC, are not suitable for insulating austenitic and duplex stainless steels.

5.3.2 Adhesives

Adhesives are used to bond insulation materials to equipment surfaces in some applications. Adhesives are also a component of tapes, prefabricated piping covers, and other prefabricated systems.

⁽⁶⁾ Nuclear Regulatory Commission, 2120 L Street NW, Washington DC 20037.

Some adhesives used on adhesive tapes have been found to cause ESCC of austenitic and duplex stainless steels. The most common problem has been the use of tape to temporarily position heat tracers or other insulation system components.

Adhesives used with labeling systems for identification are of concern because of the effects of chloride content and crevices.

5.3.3 Mastics and Coatings

Mastics and coatings are applied over insulation materials for weather protection and as cold service vapor barriers where metal or other jacketing is not used. Irregular shapes, such as pumps and valves, are typical applications.

Weather resistance and maintenance of these materials must be considered when they are used to provide primary weather protection. Periodic inspection and repair of damage are necessary to maintain the usefulness of these materials.

5.3.4 Sealants and Caulks

Sealants and caulks are used to seal protrusions through insulation systems and to provide vapor barriers in below-ambient conditions.

Failure of sealant and caulking systems is a common source of water intrusion into insulation systems. Weather resistance, maintenance, and suitability for the service temperature must be considered. Periodic inspection and repair of damage are necessary to maintain the usefulness of these materials.

5.3.5 Jacketing Materials

Jacketing materials are used to provide mechanical and weather protection for insulation systems. Commonly used materials include aluminum, aluminized steel, galvanized steel, stainless steel, fiberglass-reinforced plastic, thermoplastics, reinforced fabrics, and tape systems.

Aluminum jacketing is economical, relatively corrosion resistant, and easy to work with, and therefore, its use is widespread. Pitting corrosion from the inside surface because of entrapped moisture and reaction with wet insulation materials is a concern. Aluminum jacketing is commonly supplied with an inner barrier of thermoplastic film and/or kraft paper, and is available with various factory-applied outer coatings for additional corrosion resistance. Pitting and perforation of aluminum jacketing negates its function as a weather barrier. Use of aluminum on high-temperature (above 595 °C [1,100 °F]), high-alloy equipment is normally restricted because of LMC concerns.

Stainless steel jacketing is available in austenitic Types 302, 304, and 316. Because it is more expensive than aluminum jacketing, its use is limited to specialized applications such as plant atmospheres corrosive to aluminum, areas where insulation is intended to serve as fireproofing, and use on high-temperature (above 595 °C [1,100 °F]), high-alloy equipment. The concerns previously discussed for ESCC of insulated austenitic and duplex stainless steel equipment with aluminum jacketing are also concerns with stainless steel jacketing in a conducive environment or in contact with leachable chloride-containing insulation. Stainless steel jacketing is commonly supplied with an inner barrier of thermoplastic film and/or kraft paper. When stainless steel jacketing is used, it should be used in conjunction with stainless steel bands and hardware to reduce the occurrence of galvanic corrosion and, at high temperatures, LMC.

Galvanized steel or aluminized steel jacketing suffers from iron-oxide staining as a result of corrosion at seams, screw holes, and other edges where the zinc or aluminum is unable to provide adequate galvanic protection. Use of galvanized jacketing above 370 °C (700 °F) on high-alloy equipment may be restricted because of LMC concerns. As with the jacketing materials mentioned above, galvanized steel and aluminized steel jacketing are commonly supplied with an inner barrier of thermoplastic film and/or kraft paper.

Nonmetallic materials such as fiberglass-reinforced plastic and thermoplastics are becoming more commonly used jacketing materials. Questions that should be addressed by users are (1) the low melting point temperature that may preclude their use as jacketing for thermal insulation or jacketing for insulation that serves as fireproofing, (2) future traffic or mechanical abuse, (3) resistance to UV light (sunlight), and (4) resistance to chemical spills.

Reinforced fabric jacketing is typically used for removable and reusable insulation covers, which are custom made for specific equipment for conventional insulation methods are impractical.

Section 6: Inspection and Maintenance

6.1 Overview

Thermal insulation on equipment creates a formidable barrier to easy inspection for corrosion damage. Unfortunately, the very presence of thermal insulation can set up corrosion problems that are completely unrelated to the product contained in the equipment.

In many instances, it is a simple task to detect and measure the effects of corrosion caused by the process fluids and gases on the inside surface of equipment, yet a very difficult task to detect and measure the effects of corrosion caused by thermal insulation on the outside surface.

Removing all the insulation would be the ideal method for locating and evaluating CUI, but this is time-consuming and expensive. Visual inspection for evidence of moisture or corrosion helps to predict where surface corrosion threatens the equipment. At the very least, it can locate suspect areas for further investigation. All plant personnel can and should help with the visual inspection and then consult with the company experts.

Many owner-sponsored risk-based inspection (RBI) programs are being used in industry. The European Federation of Corrosion (EFC)⁽⁶⁾ has issued EFC 55,²⁶ which covers one RBI method in depth.

6.2 Preinspection Activities

A plan should be developed to inspect and record warning signs of CUI. It is helpful to begin with a plant or area map indicating location of equipment. For process piping, refer to API⁽⁷⁾ 570.²⁷

The map should be used as a point of departure to prioritize, inspect, and record suspect insulation. The following list should be used in setting priorities, and a separate prioritizing checklist should be used for each item of equipment.

⁽⁶⁾ European Federation of Corrosion (EFC), 1 Carlton House Terrace, London, SW1Y 5DB, U.K.

⁽⁷⁾ American Petroleum Institute (API), 1220 L St. NW, Washington, DC 20005-4070.

6.2.1 Location of Equipment

6.2.1.1 Is it indoors or outdoors?

Inside areas are less at risk for CUI, provided that they are not near hose-down, safety shower, or fire protection deluge systems.

6.2.1.2 Does the prevailing wind contain high humidity or corrosive contaminants?

Equipment downwind of corrosive mists (e.g., cooling tower, power plant, and seashore) is more exposed to CUI factors.

6.2.1.3 Is equipment susceptible to mechanical damage?

Insulation systems bumped by tools or used as mechanical support for workers are more likely to break down and allow water entry.

6.2.2 Temperature and Materials of Construction

6.2.2.1 How susceptible is the substrate metal to corrosion or ESCC at operating temperatures?

The probability of material failure varies with operating temperature or range of temperature. The following are the temperature ranges of greatest concern.

6.2.2.1.1 For carbon steel, continuous process operation at external metal surface temperatures between -4 and 175 °C (25 and 350 °F) or cycling through the atmospheric dew point.

6.2.2.1.2 For austenitic and duplex stainless steels, continuous process operation at external metal surface temperatures between 50 and 175 °C (120 and 350 °F) or cycling through the atmospheric dew point.

6.2.3 Age of Equipment

6.2.3.1 How long has the equipment been in service since last insulated?

Because CUI is an insidious problem, it is helpful to check records for when the equipment was installed or last insulated. CUI problems are commonly found to be significant after about five years.

6.2.4 Coatings

6.2.4.1 Is equipment coated?

Coated equipment has a better survival rate, but the type of coating system used should also be considered. Coating systems suitable for liquid immersion service are usually specified, and guidelines for selection of protective coating systems are in Section 4. Insulated equipment that has been coated is much easier to inspect.

Special attention should be paid to assessing coating system integrity at field welds.

6.2.5 Risk Potential—Process/Business/Environment/Safety/Health

6.2.5.1 Are there exposed fittings?

Fixtures such as clips, nozzles, and inspection ports needing caulking are potential points for water entry. A change of design is sometimes the only solution.

6.2.5.2 What are the consequences of a leak?

In choosing the frequency of inspection, the owner should consider the environmental and economic consequences of a leak. Also, OSHA^(®) 29 CFR 1910.119²⁸ (or similar local standards) should be used as a guide.

6.2.5.3 What is the cost of downtime for repairs or replacement? Should key items of equipment be inoperable for several weeks? Several months?

6.3 Visual Inspection

6.3.1 New Construction

Design and specification documents should be reviewed to make sure they are complete and correct. Adequate resources must be devoted to ensure that the design details are properly implemented. Visual inspection of the insulated equipment in the work area should be started using the site map, the prioritizing checklist, and an inspection work sheet. Equipment designated to be coated should be checked to verify that it has been coated according to manufacturer's or owner's specifications. Suspect areas should be recorded. The following guidelines should be adhered to, as CUI may occur when they have not been followed:

- (a) Keep insulation dry at all times.
- (b) Keep surfaces to be insulated clean and dry.
- (c) Ensure that a full bedding coat of asphalt cutback is applied when required.
- (d) Use the insulation thickness designated in the project insulation specifications.
- (e) Determine whether the insulation should be single-layer or double-layer.
- (f) Ensure that all insulation joints are staggered, especially on double-layer systems.
- (g) Ensure that a bedding coat has been applied between the first and second insulation layers for systems operating below -40°C (-40°F). Do not apply the coat to the metal substrate.
- (h) Ensure that the insulation has no gaps greater than 3.00 mm (0.125 in).
- (i) Replace the affected section of insulation if the gap exceeds 3.00 mm (0.125 in). Do not use finishing cement to fill the gap.
- (j) Use valve stem extension handles, where applicable, for insulated valves.
- (k) For systems requiring a vapor barrier, ensure that the vapor barrier has been applied to the exterior of the insulation.
- (l) Do not use screws to secure jacketing on systems with vapor barriers.
- (m) Ensure that insulation has been secured with the specified wire, bands, or tape.
- (n) Ensure that all insulation terminations have end caps.
- (o) Ensure that watershed angles are provided.
- (p) Ensure that installed insulation is protected from rain and washdown until jacketing is installed.
- (q) Ensure that the proper jacketing type and metal thickness is installed.

^(®) Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, 200 Constitution Ave. NW, Washington, DC 20210.

- (r) Ensure that the jacketing is installed in watershed fashion on horizontal runs.
- (s) Ensure that the bands and breather springs are the correct size and material. These are installed on the outside of the jacketing around the equipment.
- (t) Ensure that the bands are turned under or caulked at the clips.
- (u) Ensure that the nozzle openings and all other protrusions are flashed and caulked.
- (v) Ensure that the system has been caulked. Caulking should be left beaded, not feathered.
- (w) Order duplicate equipment nameplates for systems operating below 0 °C (32 °F). These should be banded, not screwed, to the outside of the jacketing.

6.3.2 Equipment in Service

Visual inspection of the insulated equipment in the work area should be started using the site map, the prioritizing checklist, and an inspection work sheet. Specific items of equipment that are coated should be identified. Suspect areas should be recorded. Inspection personnel should be alert to the following warning signs:

- (a) Weathered, damaged, inelastic, or missing caulking.
- (b) Weathered, split, or missing mastic moisture barriers.
- (c) Punctured, torn, loose, dislodged, slipped, missing, or corroded metal jacketing.
- (d) Stains, deposits, or holes in jackets and covers.
- (e) Unsealed piping terminations.
- (f) Gaps in jackets around piping hangers, at the tip of vertical piping runs, and at other protrusions such as structural stainless steel supports.
- (g) Swollen or blistered insulation.
- (h) Improper installation interfering with water run-off.
- (i) Mildew or moisture at insulation support rings or vacuum rings.
- (j) Unprotected insulation where parts have been removed.
- (k) Unsealed metal wall thickness test points.
- (l) Flashing that does not shed water.
- (m) Open joints in jackets from physical damage.

6.4 Nondestructive Moisture and Corrosion Detection Techniques

The following techniques and devices may enhance visual inspection on any type of insulation. On some equipment, the CUI pattern may be nonuniform, and spot nondestructive evaluation (NDE) may be misleading.

- (a) Moisture meter;
- (b) Infrared thermography;
- (c) Neutron backscatter device;
- (d) Flash radiography;
- (e) Electromagnetic (e.g., pulsed eddy current);
- (f) Ultrasonic testing (UT);
- (g) Fluoroscopic imaging;
- (h) Profile radiography; and
- (i) Guided wave ultrasonic testing.

Other techniques may also be appropriate. Users' options are not limited to the above list.

6.5 Assessment of Damage

If investigations or observations indicate wet insulation, the extent of corrosion or structural damage to the equipment must be assessed. Insulation should be re-

moved or the corrosion should be evaluated by a suitable NDE technique. Some of the techniques are listed in Paragraph 6.4.

The following procedure may be used for assessing the damage:

6.5.1 Remove a patch of insulation, 12,000 to 15,000 mm² (18 to 24 in²) in area, from vessels or piping greater than 610 mm (24 in) in diameter, or a section approximately 1 m (3 ft) long from piping less than 610 mm (24 in) in diameter, where there is probable corrosion damage. Site-specific requirements must be followed when removing asbestos, respirable ceramic fiber (RCF), or nonasbestos respirable fiber (NARF) insulation.

6.5.2 When repeat inspections are to be made at the same point, use replaceable insulation plugs to close inspection holes in the insulation.

6.5.3 Examine the equipment for thick rust deposits on carbon steel and hard, crusty deposits on austenitic and duplex stainless steel. Corrosion is often found above vacuum rings and insulation support rings, above and below manways, and below breaks in top head moisture barriers.

6.5.4 If there is no corrosion and the insulation is dry, replace the insulation and seal thoroughly.

6.5.5 If there is no corrosion but the insulation is wet, remove the insulation to the point where it is completely dry. Eliminate the source of water intrusion, using proper insulation installation techniques.

6.5.6 If corrosion damage has occurred, remove all the insulation from the damaged areas. The total system must be inspected and cleaned. The damaged equipment or parts must be repaired as necessary or replaced. The metal surface must be protectively coated and reinsulated.

6.6 Equipment Inspection Methods

6.6.1 Carbon Steel

Ultrasonic thickness and pit depth measurement techniques are usually used to determine the remaining wall thickness of equipment when there is direct access to the exterior surface. Testing should be performed using established test procedures such as those in API 510,²⁹ API 570, and API 653.³⁰

6.6.2 Austenitic and Duplex Stainless Steel

6.6.2.1 Eddy Current Testing

Eddy current testing (ECT) should be used for inspection of austenitic and duplex stainless steel surfaces. When properly used, ECT is a rapid, effective method for detecting ESCC. ECT must be performed by qualified specialists.

6.6.2.2 Liquid Penetrant Testing

When ECT is not practical, liquid penetrant testing (PT) is a useful procedure for ESCC detection. The metal surface must be as near ambient temperature as possible. PT is not effective at elevated temperatures. The periphery of cracked areas should be examined for less obvious cracking, especially if weld repair is being considered. Only halogen-free PT materials should be used.

6.6.2.2.1 Surface Preparation and Cleaning

6.6.2.2.1.1 The stainless steel surface should be prepared for PT by one or more of the following techniques to remove surface deposits and to avoid peening shut any ESCC.

- (a) Wet abrasive blasting—An effective surface cleaning procedure for PT of stainless steels is wet abrasive blasting to remove deposits and minimize dusting.
- (b) Disc sanding—This may be done with coarse grit and moderate pressure. Too much pressure forces grit into cracks.
- (c) Flapper sanding—This may be done with coarse grit and moderate pressure.
- (d) Pencil grinding—This may be used to prepare fillet welds where a sander cannot reach.

Conventional dry abrasive blasting should not be used. Grit blasting may remove the telltale brown stains often indicative of ESCC, smear over the cracks, and decrease the effectiveness of the PT.

6.6.2.2.1.2 The prepared area should be washed with water, cleaned with chloride-free solvent, and wiped dry with a lint-free cloth. Liquid (red dye) penetrant should be applied by spray or brush on ambient temperature surfaces, allowing 15 min to penetrate. Excess penetrant should be wiped off with a lint-free cloth soaked in chloride-free solvent. A very thin coating of developer should be applied followed by visual inspection after at least 10 min for indications of cracking.

6.7 Repair

The extent of damage should determine the type and amount of repair required. Before beginning repairs, a qualified corrosion/materials specialist should be consulted to assist in assessing damage and choosing repair methods. Methods must be consistent with good practices and code requirements. Examples of repair techniques and insulation refurbishment practices include:

6.7.1 Replacement of equipment may be necessary if its integrity is affected by severe corrosion of carbon steel or by ESCC of austenitic and duplex stainless steel.

6.7.2 Repair of equipment that has corroded must follow the requirements of applicable codes and standards. These include the ANSI⁽⁹⁾ National Board Inspection Code (NB-23),³¹ API 510 for pressure vessels, API 653 for tanks, and API 570 for piping.

⁽⁹⁾ American National Standards Institute (ANSI), 25 West 43rd St., 4th Floor, New York, NY 10036.

6.7.3 Replacement of deteriorated caulking with silicone caulking compounds.

6.7.4 Replacement of flashing around vacuum and insulation support rings, and clips as well, with types that direct water away.

6.8 Shutdown and Mothballing

Some severe cases of CUI have occurred during extended shutdowns or mothballing of equipment. Weather barriers deteriorate during these idle periods, and typically, no maintenance or repair is performed.

Carbon steel equipment may be severely corroded at ambient temperature when mothballed. Austenitic and duplex stainless steels are susceptible to ESCC by the water-leached salts when the equipment is returned to service after idle periods; however, it is not likely to corrode under insulation during storage.

When plant management is uncertain whether equipment will be used again, funds or facilities to maintain weather barriers or to move equipment indoors may not be provided. Stripping all insulation before mothballing is the most cost-effective way of storing carbon steel and stainless steel equipment. As a rule, rusting of exposed carbon steel is less severe and more uniform than corrosion under wet insulation.

Stored equipment should be abrasive-blasted, recoated, and reinsulated before use in a CUI environment.

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