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Control of Corrosion Under Insulation

By Patrick J. Dunn, Associate Member ASHRAE, and **Richard Norsworthy**

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Corrosion under insulation is a major problem. When insulation becomes wet (because of poor installation practices, subsequent abuse or failure to specify good vapor barrier and waterproofing materials), it "creates the potential for corrosive failure of the piping."[1] Whether pipes are above ground or buried, proper design and installation techniques can control corrosion.

Basic Corrosion Control

The sidebar discusses the four necessary elements for the corrosion process to occur. However, certain external factors will cause variance in the corrosion *rate* after the corrosion process begins. Examples of factors affecting corrosion rate would be hot/cold cycling expansion and contraction (stress cracking) and wet/dry cycles.

The most effective way to control corrosion is to prevent the electrolyte from reaching the metal surface by applying a corrosion coating or tape on the pipe. Government regulations require oil and gas companies to coat (with coatings and/or tapes) any pipeline before it is buried. Cathodic protection is also required to prevent corrosion on pipes where coating damage may occur, or that may not have been properly coated leaving voids under the coating or tape. Cathodic protection is the installation of *external* sacrificial cathodes of a lesser metal and a low voltage current on a piping system. This is *required* by the U.S. Department of Transportation on all oil and gas transmission lines that are *not* insulated. The purpose is for the external metal to sacrifice itself in place of the anodes in the pipe.

The oil and gas industry has used pipe coatings and tapes successfully for many years. These vary in type, from the first coal tar brush on coatings covered with a spiral wrapped bitumen tape, to today's epoxy, urethane, urea, and FBE (fusion bonded epoxy) coatings.

The pipeline industry (loosely defined as the oil and gas industry and the *uninsulated* piping used as transmission lines) and the insulation industry (dealing with *insulated* piping systems) differ in their practices in some respects, but the success and growth in the pipeline coating industry raises the question of why other industries are not using this knowledge to protect pipes and process systems.

Pipeline coating obviates the need to replace piping systems every few years, avoiding the cost of such expensive projects. It also prevents conflict with environmental groups, the U.S. Environmental Protection Agency and local government.

Coating Selection Considerations

The proper selection of coating materials is important. When selecting coatings for metals under insulation, consider:

- System operating temperatures,
- Application and site requirements,
- Surface preparation requirements,
- Environmental requirements during surface preparation and application, and
- Compatibility with insulating materials.

System Operating Temperatures

A coating has to be flexible enough to

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withstand the expansion and contraction of the piping system when temperatures cycle. Temperature fluctuations can cause a loss of adhesion between the coating and the metal, which allows water to reach the pipe. High temperatures can cause certain coating types to flow, crack, or sag. Low temperatures can cause some coatings to become less flexible or brittle.

Some coatings work well at cold temperatures, while others work well at high temperatures. New entries into the metal protection industry have achieved temperature ranges between –320°F and 350°F (–196°C and 177°C), with prospects of coatings up to 900°F (149°C) for specialized applications on equipment that cycles from cold or ambient up to higher temperatures. This cycle accelerates the corrosion process.

Application Requirements

Some types of coatings require extensive surface preparation, even heating the pipe before applying the coating. Other coatings can be applied with minimal surface preparation and application equipment. Field application becomes more difficult because of confined space, safety, and environmental concerns. Inspection to ensure proper coating coverage and thickness is cumbersome.

Liquid coatings can be applied by brush, glove, or spray method (e.g., air, airless, or plural component). Tape coatings can be applied in a "cigarette wrap" or by spiral wrapping by hand or machine. On insulated systems, tapes will affect the inner diameter (ID) and the fit of the insulation. Some types of tapes are applied using heat, usually a propane torch. Powder coatings, such as fusion-bonded epoxies (FBE) are applied to a hot (normally 450°F to 488°F [232°C to 253°C]) pipe surface and are applied in a specialized pipe coating plant with temperature and humidity control.

Surface Preparation

Surface preparation is the most critical part of any coating process. Care must be taken to perform the best possible surface preparation for the application. Experts in the coating industry advise that two-thirds of the cost of any good coating job should go into surface preparation.

Blasting with an abrasive helps to clean the surface and provides the proper anchor pattern to which the coating will adhere. Before blasting, any oil, grease, or other debris must be properly removed. Blasting only spreads oil and grease contamination—it does not remove it. Contaminants on the metal surface, such as chlorides and other salts, must be removed by proper washing and rinsing techniques. Mill scale, rust, and other such surface contaminants can usually be removed by proper blasting. Wire brushing by hand or machine is acceptable for some types of coating. Water blasting, with and without abrasives, may be used in other situations. This must be performed with the proper methods and equipment.

The introduction of mineralization surface conversion technology (see sidebar) in the insulation industry reduces the amount of surface preparation required before installing the compound. Sand blasting is not necessary, even on rusted pipes. The main requirements are to remove oil or salt films that may be on the pipe surface and the removal of scale rust with a wire brush, or water blasting.

The type of surface to be coated dictates the type of surface preparation and coating to be used. New carbon steel can be cleaned and blasted easily, compared with corroded or pitted steel in used systems. Corroded or used metal systems may have surface contaminants such as chlorides or salts that must be properly removed before blasting. Stainless steel surfaces

The Corrosion Process

Metal corrosion requires four elements: an anode, a cathode, an electrolyte (e.g., moisture), and an electrical path (e.g., metal) joining the anode and cathode.

The anode is the part of the metal where corrosion occurs. It actually sacrifices itself as it releases positively charged metal ions into the electrolyte and electrons are left behind in the metal. These electrons flow through the metal to protect the cathode. The cathode is protected because various ions or compounds in the electrolyte consume electrons.

An electrolyte is a solution capable of conducting electrical current in the form of ionic flow. An electrical path is a connection between the anode and cathode where current in the form of electrons can flow. Free electrons do not flow in the electrolyte, only in a metal path.

Corrosion occurs because anodes and cathodes are inherent in *all* metals, and *all* metals are electron conductors. Anodic and cathodic components can be microscopic in size or rather large in some cases. Therefore, *three of the four requirements for the corrosion process are inherently present in every metal*. The only remaining element required for the corrosion process to begin is an electrolyte.

Anodic and cathodic areas develop where chemicals have deposited, where there are temperature differences, and where there are damp areas. Chlorides and other industrial contaminants in the electrolyte can cause an area to become anodic. The contamination may be present on the metal surface before it is coated or insulated. Once these areas become wet, corrosion begins.

The corrosion of metals requires the following conditions:

- An anode, a cathode, an electrical path, and an electrolyte must all be present;
- The anode and cathode must be in contact with the same electrolyte;
- The metal must electrically connect the anode and cathode for electrons to flow; and
- The anodic (oxidation) and cathodic (reduction) reactions must be equivalent and simultaneous.

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are very hard, making it difficult to create an anchor pattern. Certain types of stainless steel should not be blasted with steel grit or shot because the carbon in the blast material itself can cause corrosion problems. Non-carbon blast materials, brushes, or grinding disks should be used instead.

Unique circumstances will dictate exceptions to any of these recommendations. Nevertheless, preparing the substrate in some way is always important. Other types of metal not mentioned here should be studied and tested to determine the most effective method of surface preparation.

Compatibility With Insulating Material

Some types of insulating materials may be abrasive (e.g., cellular glass), and as the pipe moves, the coating material will be damaged. Other insulating materials may cause the coating to deteriorate, become soft or brittle, or lose other properties (especially if the insulation becomes wet). The thickness of most coatings is within the ID tolerance of insulation products. However, insulation fabricators may have to alter some tolerances of the ID of their insulation to provide products that fit over certain coatings. Coating selection and insulation characteristics should be considered jointly when specifying a system. In their wet state, some corrosion coatings react with fabricated foam insulations; therefore, coatings must be allowed to cure completely before installing insulation.

Testing

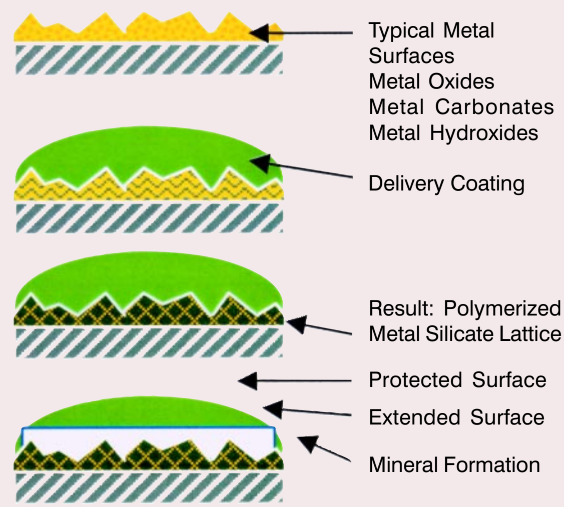
The pipeline industry has developed an effective way to provide good unbiased information about products to its constituents through an industry-sponsored testing program, most "off the shelf" products available have these test results available. The industrial refrigeration industry, the commercial insulation industry, and industrial insulation industry should consider the same.

Product Selection

Currently, the market offers a variety of coating products and materials. All of the considerations that must be taken into account make product specification confusing. Vendors can be helpful in providing information, and technical support from the coating manufacturer and is recommended for new systems. Again, the NACE Web site and corrosion articles provide a wealth of knowledge concerning corrosion testing and product comparisons after testing.

Specifications

A well-written specification that details the coating process is crucial in any corrosion coating project. Specifications should include surface preparation requirements and application parameters. Each coating system must have its own specification, and each project must be carefully specified. The specification is *not* "one size fits all."



Surface Conversion Technology (Minetics)

Surface conversion technology, or minetics, is the ability to grow very thin minerals on metal surfaces for useful purposes. Engineered surfaces form when mineral-forming reactants are delivered to the surface of a metal or metal containing article via novel modifications of known base formulations (e.g., paint, gel, grease, aqueous suspension).

Substrates contribute donor ions to react and/or interact with delivered reactants, forming a very thin layer of mineral that chemically bonds to the surface of the substrate that has been measured to be a few monolayers thick. In many applications, lattice-forming oxides anchor to this surface-adhesion layer and polymerize into a three-dimensional inorganic framework structure until the final coating thickness is 50–200 angstroms.

Engineered mineralization products have been developed to deliver the mineral-forming reactants in a variety of formulations including paints, coatings, synthetic gels, greases, thread dressing, sealants, adhesives, and water gels.

Inspection

To ensure that the coating and surface preparation processes are properly performed, in progress inspection is a must. Inspection ensures that the surface preparation and coating process is properly performed in the right conditions at the correct thickness and that it has been allowed to properly cure. Voids or thin spots in coatings are potential corrosion sites, special "holiday" detection devices are available to detect these voids, and these areas should be identified and repaired before insulating. Mineralization conversion technology is quite forgiving and voids can exist without detrimental affect.

Many people associate corrosion coatings on pipes or vessels with house painting and assume that the process is that

(Left) Brush application of coal tar coating. (Right) Rubberized bitumen tape applied to steel pipe.

simple, it is not.

In the insulation industry, coatings are rarely specified on the pipe and protection of the system is provided by the vapor retarder jacket and/or mechanical jacketing. Mineralization technology gels are superior under insulation as they will buffer moisture that may enter the system, making it harmless to the pipe itself. This process of buffering raises the pH of water to create a passivating environment.

Types of Coatings

Types of coating choices on the market include:

- Liquid coatings: epoxies, urethanes and polyureas,
- Tapes and shrink sleeves,
- Brushable coal tar or asphalt-based corrosion coatings,
- Mineralization coatings, and
- Fusion-bonded epoxies and multilayer coating.

Liquid epoxies are excellent choices for coating pipes. Basic epoxies are two-component materials that are mixed and normally applied by spray or brush. Some epoxies are applied with multicomponent equipment that mixes the components at the applicator gun. Epoxies must be mixed in the proper ratio. If the mixture is not correct, the epoxy does not cure properly or perform well. Specific environmental concerns need to be addressed since fumes and cleanup are important criteria.

"Phenolic epoxies are excellent coatings for higher-temperature applications up to 300°F (149°C). Modified epoxy phenolic coatings offer good abrasion resistance and are more flexible than most epoxy phenolics."[2] Phenolic epoxies are applied by experienced applicators using heated multicomponent equipment.

Urethanes and polyureas are also excellent coatings for cold process piping and vessels. Most urethanes have limited use for higher temperature operations at greater than 150°F (66°C). Urethanes are flexible and can be applied in one thick coat with a heated spray system. Moisture can be detrimental to some urethane applications, but moisture-cure urethanes perform well for applications where moisture is a problem during application.

Certain types of corrosion-control tapes provide excellent corrosion protection for pipes on systems that operate at temperatures of 150°F (66°C) or less. Tapes are relatively easy to apply. Most require a primer in order to adhere properly to the pipe, and the primer must cure properly before the tape is applied. Tapes vary from 25 to 100 mils in thickness, thus, the insulation material must have the proper ID to enable the insulation to fit over the tape.

Asphalt or coal tar-based materials do not require mixing, thinning, or other special treatment. They are easily applied by brush or paint glove in one or two coats. Surface preparation requirements are not as stringent for these materials as they are for many other coatings. These coatings are good for irregular shapes, are flexible, adhere well to the steel, are resistant to most chemicals, and can be repaired easily. They have fair abrasion and impact resistance. They do require a certain amount of time to cure properly. At temperatures below 0°F (–18°C), this type of coating may become less flexible; at temperatures above 120°F (49°C), some of these coatings may become too soft or tend to run to the bottom of the pipe.

Mineralization Conversion Compounds

Mineralization conversion compounds are new to the insulation industry. As the name implies, these coatings create a mineralization bond with a pipe, a "new" surface. They can be effective on systems at temperature ranges from –50°F to 250°F (–46°C to 121°C). Excess coating from the application acts as a reservoir in the event of mechanical damage to the mineral layer, or the intrusion of an electrolyte. Corrosion *cannot* take place in this mineralized layer on the pipe.

The greatest benefit of this type of technology is if the vapor barrier is compromised and moisture enters the system, it can travel directly to the pipe's surface and remain there without corrosion taking place. The excess coating from the installation process chemically binds the water (buffering it) so that it cannot corrode the pipe. Only removal of the excess coating with cleaner can alter the protection provided to the piping system.

Mineralization surface conversion compounds can be applied to all types of pipes. They not only prevent corrosion but also prevent stress cracking when applied to copper or stainless steel systems.

Mineralization surface conversion compounds are effective

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(Left) Insulated pipes in a 5% aerated salt bath. (Center) Same pipes 365 days into test. (Right) Pipe inspection after 365 days in salt solution. No corrosion in surface conversion treated areas.

on new piping, valves, tanks, vessels, and appurtenances. This type of compound is equally effective in the retrofit market where reinsulation of compromised systems normally requires replacing corroded pipes, fittings, valves, or other components. Conversion compounds can obviate the need to replace piping that is somewhat corroded but will remain intact if no further corrosion occurs. In the past, this was not an option. If the metal retains sufficient physical integrity for the pressures it contains, it can be wire brushed or water blasted to remove any loose rust scale or corrosion scale before the pipe is treated with the conversion compound and reinsulated. This type of application will create the same mineral bond in old piping as new.

The use of surface conversion compounds will revolutionize corrosion control on below-ambient systems under insulation. The life expectancies of these systems will be increased, and with proper insulation, vapor barrier, and mechanical protection. Corrosion is not a problem *only* on below ambient piping systems, however the 250° F (121°C) temperature limits of conversion compounds limits them primarily to below ambient systems where moisture drive to the pipe can occur.

Rehabilitation of Existing Systems

Rehabilitation of insulated piping systems can be performed with many of these coatings. For systems where surface preparation is difficult and minimal surface preparation is performed, mineralization conversion compounds are the best option. Tapes are an option if the fabricator can supply insulation with the proper ID. Brushable coal tar and asphalt-based coatings can be considered. Retrofit conditions usually do not permit spray application, limiting your options.

The most cost-effective method for rehabilitation without replacement is the minimal cleaning required by mineralization surface conversion technology. Removal of loose scale with a brush or water jet is sufficient preparation prior to installation of mineralization coatings. Though this technology may appear new to many, it has been used in military and automotive applications for more than 15 years with proven histories for mechanical uses such as anti-seize on flange bolts, anti-corrosion on moving parts such as bridge rockers, and anti-corrosion of protected, yet concealed steel cable.

Insulation

The insulations used for above freezing yet below ambient piping are quite broad including fiberglass, elastomeric plastics, elastomeric rubber, mineral wool. It also can include subzero insulations such as polyisosyanurates, polystyrenes, cellular glass and phenolics. Surface conversion compounds are less attractive for chilled water systems as failure of these systems due to corrosion is not an environmental issue as much as a possible property damage issue. Failures of chilled water systems can occur within five years due to advanced corrosion activity. The use of surface conversion compounds would eliminate such early demise of the piping system, however, conversion gel manufacturers will not put a figure on it as the choice and installation of ALL components in the system contribute to the life of the system.

Insulation types are fairly limited for below-freezing piping systems; cellular glass, polyisosyanurates, polystyrenes, and phenolics are normally the insulations of choice. The manufacturers of these products publish technical literature that describes their uses, temperature limitations, and design criteria. The job criteria (atmospheric conditions, process system, and plant environment) should determine the insulation best suited to a specific job. The fact that an "ammonia system" is being designed is not enough information on which to base an insulation specification. Although the basic design criteria of the system may be known, the environment into which the system is being installed must be considered before specifying types of insulation and insulation thicknesses.

Insulation thickness is *critical* to the success of the system. Worst-case atmospheric job conditions should be used when calculating insulation thickness. This condition may only exist one week per year, but that single worst-case could create a corrosive environment that eventually could cause the premature demise of a system.

Installation of the insulation is as critical as the choice of

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insulation itself. Improperly sealed insulation can allow moisture to migrate to the pipe, providing the electrolyte necessary to begin the corrosion process.

Insulation manufacturers literature normally suggests perm-rated joint sealants for their insulations. It is important to use joint sealants to slow the migration of water vapor to the pipe if a breach in the vapor barrier occurs. Since there are atmospheric conditions present during all installations, water vapor will be trapped in the system when the vapor barrier is sealed. Consulting with an insulation fabricator is helpful given how closely fabricators work with the insulation manufacturers and how frequently they deal with insulation specifications on cold piping systems.

Surface Conversion Application

Mineralization surface conversion compounds are designed to be bead applied to the bore of the inside layer of insulation by the insulation fabricator to minimize installation cost. The number of beads in the ID of the insulation depends on the pipe size being insulated. A bead is also applied at one end of the insulation piece to act as "insurance" at every joint. Due to the physical properties of the compound, it can be applied and shipped to the job site without sagging or skinning over.

The installation process is simple. The insulator installs the pipe cover and rotates the insulation around the pipe and longitudinally to distribute the compound onto the pipe. The beauty of the buffering system is that 100% coverage *is not critical*. Using this installation method, testing shows that coverage of better than 98% is achieved with this rotation and sliding of the insulation.

Application of rubberized bitumen vapor retarder/weather barrier membrane on ammonia refrigeration piping system.

Vapor Retarders and Protective Jackets

One of the most critical components on cold systems is the vapor barrier, or vapor retarder as commonly stated. Vapor barriers, or retarders, come in various forms. They include products such as ASJ paper, FSK paper, vapor barrier mastic, Mylar's, proprietary polymers, and laminated self-adhesive membranes. The recent introduction of *low*-perm, peel-and stick, *self-healing* vapor barrier membranes are just what the doctor ordered! Although the cost is approximately three times that of ASJ paper (a retarder), cost should not deter the specification of these membranes! These new membranes are UV stable *indoors* and can eliminate the need for an additional mechanical jacket, (making them comparatively less expensive) where mechanical protection isn't required.

For exterior applications, laminated rubberized bitumen self-sealing membranes have been produced with various "skins" to make them impervious to the elements.[3] These membranes eliminate the need for expansion slip joints by providing 400% elongation before rupture; they expand and contract with the system. Insulation can be applied, and then one peel-and-stick jacket provides an excellent perm rating (0.00046 US perms), ultraviolet stability, excellent emissivity, and sealed weather protection.

Currently, the standard specification is for a vapor retarder jacket to be installed under a protective mechanical jacket, such as PVC or Aluminum. The vapor retarder of choice is most commonly ASJ paper, which, if "crinkled" has lost its vapor retarder properties. Furthermore, the seal on a metal or PVC jacket is only as good as the installer is with the glue gun or caulking gun. Engineers also are finding that expansion and contraction of piping systems with PVC or metal jacketing can generate friction between the vapor retarder and jacket, eventually wearing through the vapor retarder.

For a below-ambient insulation system to be successful and not contribute to the corrosion process, it must be specified in the following manner:

- Using a corrosion control coating or treatment,
- Tailoring the insulation to the application *and* environment,
- Calculating adequate insulation thickness,
- Properly sealing the joints,
- Applying a superior vapor barrier, and
- If necessary, install a mechanical jacket to protect vapor barrier from physical abuse.

To be specific, the ultimate system available today would be a joint-sealed, closed cell foam insulation, bore coated with a mineralization conversion compound, sealed with a self-healing low-perm vapor barrier and mechanically protected with an aluminum or PVC jacket where necessary for mechanical abuse protection. Exterior systems would be jacketed with self-healing, vapor barrier membrane without a mechanical jacket. The cost of such a system would be approximately 30% higher than typical systems being installed today.

Comments have been made about the insulation industry and how difficult it is to change the status quo, if the industry wants to solve this serious corrosion under insulation problem, it has to change the specification and installation processes. Engineers must work closely with fabricators to find solutions to this aspect of the problem; it is not beyond a fabricator's capability. Communication levels among engineering entities and insulation fabricators, installers, and manufacturers must increase. Alternate innovative products are not

For More Information

Corrosion Testing
- www.nace.org

Coatings
- www.micainsulation.org/standards/index.html
- www.insulation.org
- www.nace.org
- www.smacna.org

Insulation Thickness
- The National Insulation Association (NIA) provides free software for insulation thickness calculations at www.pipeinsulation.org.
- The Midwest Insulation Contractors Association publishes an excellent installation reference tool, *National Commercial & Industrial Insulation Standards,* available in book and CD form, (www.micainsulation.org/standards/index.html), which contains detailed drawing plates and informational tables for the insulation industry.

always submitted under the guise of increasing a contractors profit margin. Better, alternative methods in the industry must be considered on their merit rather than on the perceived intent of the presenter.

Conclusions

Coating the pipe before insulation is applied will not solve *all* of the corrosion problems that exist in this industry, but it will result in definite improvements. Through testing, proper selection of materials and methods, and well-written and detailed specifications, tremendous improvements can be made in controlling corrosion problems. The following suggestions are recommended for industry:

- The industry must be committed to preventing corrosion (primers or no coating are unacceptable);
- Testing and insulation specifications must be developed and must outline specific coating systems for each application;
- Inspection and testing must be performed; and
- Only the best vapor barriers, waterproofing materials, and insulations should be used.

On most projects, the initial cost to properly prepare, coat, and install insulation and vapor barriers is minimal compared with the overall project cost and *invaluable* when considering the cost of repair or replacement and re-insulation of corroded systems (not even considering the losses in production due to system downtime). Systems installed today that are "value engineered" make obsolescence an integral part of a system. Reducing corrosion failures results in significant long-term financial benefits. The safety and environmental issues related to these failures must also be factored into the cost savings.

References

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