Risky Business

Using a Risk-Based Inspection Program to Anticipate CUI Issues

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Photo: Art Wager / Getty Images

Ever since the days of World War I, when many of today's petroleum refineries along the Texas and Louisiana Gulf Coast first started operation, the "standard" industrial insulation system for process vessels and piping has been a corrosion under insulation-resistant coating over the steel, an appropriate thickness of insulation material over the coated steel and a thin sheet metal jacket. As the decades passed, many things have changed, but the basic concept of the insulation system has remained, though with some updates to the products used.

Petroleum refining is basically a large, industrial-scale cooking process. Crude oil is heated, alone or with certain catalysts, and after proper time and temperature, the separating components are drawn off, either to be sold as is, or for further processing. At the end of a typical refinery train, a heavy black tar residue is about the only thing left of the original crude oil, and even that is sold off for road topping or roofing asphalt.

Refinery process vessels and piping are insulated for several different reasons. The most important is process stability; the process vessel and its contents must be maintained at a uniform internal temperature so that the resulting separated product is also uniform. Other reasons are for process and personnel safety, fire resistance, cost savings on heating or cooling fuel and ease of handling—some oil components tend to gel at lower temperatures, clogging transfer pipes and tank drains, not to mention the problems of having to remove two or three feet of solidified petroleum product from the bottom of a 200-foot-diameter tank.

This article will review some of today's most popular methods for mitigating CUI—through the use of coatings, insulation materials and jacketing—and how employing a risk-based inspection plan can help anticipate potential problems and plan to address them accordingly.

CUI COATINGS

Back in the 1920s, and to a great extent today, the protective heart of the insulation system was the corrosion-resistant coating. At the heart of the original coatings was red lead, the same anticorrosive used on most metalwork then and going farther back to the steam-driven start of the industrial age. Red lead is a very good anticorrosive; unfortunately, the resins available back then did not have the required temperature tolerance for petroleum processing. Because of necessity, most early red lead primers were composed of the lead floated in just enough oil to make the resulting paste fluid enough to handle. During elevated temperature operation, the oil would burn out, leaving a thin layer (and sometimes a not-so-thin layer) of the red lead paste.

The first truly elevated-temperature resins suitable for CUI coatings were silicone and ethyl silicate inorganic zinc. Silicone resin will with stand temperatures of 1,000 F but cannot be built into a thick film. Single coats are typically 1–1.5 mils dry film thickness, and anything more than three coats thickness will crack badly in cyclic service. Pigmented with aluminum flake, silicone will give an overlapping, roof-shingle effect, which should reduce water penetration to the substrate, but the dry film thickness is too little to provide meaningful protection.

Inorganic zinc, typically applied at 3 mils' dry film thickness, is a sponge-like ethyl silicate structure filled with zinc dust. Inorganic zinc was originally developed as an exterior coating for uninsulated pipeline pipe, and early formulations contained a significant amount of lead mixed with the zinc dust, which gave an extra level of protection, even after the zinc had dissipated through anodic sacrifice. The ethyl silicate structure is stable far beyond 1,000 F, but the melting point of zinc is 780 F. An inorganic zinc coating does not have enough zinc for the molten metal to flow, but the dust has so much surface area and the silicate matrix is open enough that at melting point temperatures, the zinc dust oxidizes. The remaining zinc oxide does not have the sacrificial anodic characteristic which makes zinc a preferred corrosion resistant coating.

Fig. 1: Thermal spray aluminum is a single-coat instant dry CUI coating with very wide temperature tolerance and good service life. TSA requires specialized inspection after application; properly applied TSA is nearly identical in appearance to fresh white-metal blasted steel. The sample panel with the penny is the TSA. *Photos: Courtesy of the Author*

An additional problem with inorganic zinc used as a CUI coating is that even at acceptable temperatures, once all the zinc dust has sacrificed as a protective anode, there is no further corrosion protection. Under insulation and jacketing, there is no easy, cost-effective way to determine whether an inorganic zinc CUI coating has completely sacrificed or is still protecting.

High-build silicone or polysiloxane hybrid coatings were developed around the turn of the 21st century. These give protection to near 1,000 F and give thick, water-resistant films suitable for cyclic service. Their limitation is that at those applied thicknesses, the dry film needs to be flexible, without cracking or disbonding, to expand and contract as the steel beneath expands and contracts. The dry film of these coatings is relatively soft and can be easily damaged during installation, insulation application or careless maintenance work.

Another recent CUI preventive system is thermal spray aluminum, otherwise known as metalizing. Thermal spray application is closer to metal brazing or arc welding than it is to spray painting. Thin aluminum wire is melted in a torch flame or electric arc, is broken into very small droplets, and is then blown onto a properly prepared steel surface. The basic process has been around for a century, but despite its appearance, the resultant film is not equal to aluminum plating for several reasons. Although there is more aluminum than in plating, a large part of it is in the form of oxides, which are slower sacrificing than aluminum plating, making the thermal spray aluminum film a suitable long-life CUI coating even if chemical-laden water penetrates the insulation system.

Thermal spray aluminum film can be applied fairly thickly—typical single-coat thicknesses for CUI are 10–15 mils. The applied coating dries hard, cools very quickly and can be handled with minimal damage almost immediately after application. The comparable work time, against a two- or three-coat liquid-applied system, in which each coat requires an overnight or longer dry time, justifies the much higher application cost. The service life of a properly applied single coat thermal spray aluminum system in CUI service is equal to or longer than the life of a two-coat or three-coat liquid applied system, but has not proven to be two or three times the life of a liquid applied system, as was initially claimed in the early 2000s.

INSULATION

The purpose of insulation is to separate a heated or cooled surface from the environment around it (usually air). Air is a good insulator when held confined and prevented from circulating. Conversely, freely circulating air is a relatively poor insulator. So, most insulation is basically a material structure which holds small packets of air in place to keep it from circulating. An ideal insulation is very light, since it is mostly air, but very structured to keep the little packets of air from escaping.

The original oil refinery insulation was asbestos, usually applied as batts held in place with chicken wire. The chicken wire rusted away from water ingress through the jacketing and asbestos insulation, but the red lead beneath it protected the steel. The insulating properties of asbestos have been known since ancient Greece, and for many decades they were the petroleum industry standard. Asbestos provided good insulation efficiency and was abundant, reasonably priced and easy to handle. Its health hazards were not fully understood until the 1970s, at which time it was quickly replaced for new installations, and, over the next two decades, removed from in-service equipment and replaced with less-hazardous insulation materials.

The American Petroleum Institute defines the three basic types of industrial insulation as fibrous, granular or cellular. Asbestos, and its closest replacements—mineral wool and glass fiber—are fibrous. Fibrous materials have good insulation value, relatively high maximum operating temperatures, and are easy to work with. Their disadvantages are that they can hold water, crush rather easily and do not spring back when crushed. Newer available versions of mineral wool insulation are treated to resist water incursion and retention, and some are now available molded and pre-shaped into blocks or curved shapes, making field installation simpler than having to cut and fit large batts to shape.

Traditional pre-cast insulating blocks and shapes are usually made from a granular insulation; granular insulation may also be used as loose filler in enclosed areas. The most common types are calcium silicate and perlite. Both come in a wide variety of sizes and shapes, so that an insulation project can be pre-engineered and then quickly assembled at the job site. Disadvantages are that the materials tend to absorb and hold water, may leach chemicals, crush easily and have limited temperature tolerance. Newer versions have chemical additives to reduce water absorption and retention and to adjust the chemistry of leachate liquids.

Fig. 2: This acrylic-spray-on insulation failed after two years from excessive film thickness or insufficient dry time between coats during application. The vessel may also have operated at temperatures beyond the acrylic resin's tolerance.

Cellular insulations are foams, sprayed on the surface to be insulated over a compatible CUI coating, or foamed into molds similar to granular insulation blocks and shapes and then installed on the equipment to be insulated. Foams can be further broken down into true foams, where the bubbles are formed by gas mixed in the liquid insulation product during application when sprayed into molds. The bubbles can vary in size, shape and thickness, and can affect the long-term performance of the foam insulation. With syntactic foams, the sprayed-on material contains pre-formed spheres of uniform size and there is no bubble-forming gas in the sprayed-on liquid material. Syntactic foams are much more durable, but contain more resin and less air, so they are lower in insulation efficiency.

The resins used to form foam insulations are uniformly limited to relatively low temperatures and have relatively low insulation efficiency values. Urethane foam is used frequently on the outsides of spherical gas storage tanks, where maximum temperatures are not a problem, the size and spherical shape would make it difficult to use other types of insulation, and the amount of insulation value required is suitably low. Phenolic, polyisocyanurate, styrene and nitrile rubber-based insulation products have similar uses. Foam insulations normally do not have metal jacketing over them.

Waterborne acrylic spray-on insulation and epoxy foam are syntactic insulations, where the resin is filled with ceramic or glass microspheres, to produce a syntactic foam. Acrylic is limited by the low per-coat dry film thickness and slow drying time. Ten- and twelve-coat systems and two weeks of drying time are often required for thick systems; a more common use is two or three coats to provide personnel protection on accessible equipment, piping and brackets or to prevent thickening of crude oil stored in tanks where cold weather is a rare event.

Epoxy syntactic foam is much more rigid than acrylic, because of the hard-setting epoxy resin, but can be applied in a single coat to several inches thickness, since the 100%-solids epoxy formulation does not require solvent or water evaporation during cure. It does not work well in cyclic service or vibration environments, but has very good impact resistance and is excellent for acoustic insulation.

Fig. 3: Poor or unfinished installation, mechanical damage and signs of abuse during access are typical of aged insulation and jacketing in refineries and chemical plants. Evidence indicating a lack of CUI inspection and lack of maintenance on these easy-access feeder runs is clearly visible.

Glass foam is a true foam, not a syntactic. As the name implies, it uses glass as a support resin, and thus has to be factory poured and shaped, because of the temperature and handling requirements of molten glass. Glass foam is the only type of industrial insulation which does not absorb water, but because glass forms the resin foam structure, it is relatively brittle. Both crushing and edge degradation from vibration and cyclic service expansion/contraction can reduce portions of glass foam to glass dust. The most common use for glass foam insulation is in cryogenic or low temperature service, both on vessels and on piping. Glass foam sections are factory pre-cut and pre-shaped, and glued together onsite, in multiple layers with temperature-suitable and relatively flexible adhesive materials.

A relatively new but very useful form of industrial insulation is silica aerogel. The actual aerogel is an extremely fine dust, 99.8% air and stable to 1,200 F. For industrial insulation use, aerogel dust is adhered to a binder fabric and shaped into batts, rolls or blankets. Silica aerogel has the highest insulation value of any currently available industrial insulation product. In practical terms, this means that one-inch thickness of aerogel may provide the same insulation value as two or three inches of other industrial insulation materials. In areas where space and weight are both at a premium, such as offshore production structures or tightly packed refinery pipe racks, aerogel can provide adequate insulation in narrow spaces where other materials could not. Aerogel is also available in removable and replaceable blankets, covered with an aluminized fabric. Other industrial insulation materials (and their jacketing) are one-time use; their removal requires replacement with expensive new product.

Glass fiber and mineral wool make up the largest volume of industrial insulation products worldwide. There are a number of specialty insulation products which each have their own little niche. Ceramic fiber is available in loose bundles or formed into blankets; the fiber itself is stable to 1,800 F and is used as packing for furnaces and similar refractory or ultra-high temperature service. Vermiculite is a granular material which has a maximum operating temperature of 2,000 F and is fire retardant. At the other end of the temperature scale, chopped cork and even sawdust can be used for service with low temperatures and no worry of fires.

JACKETING

Industrial insulation materials are uniformly lightweight and generally flimsy, because their purpose is to hold a lot of little air packets in place with a minimum of resin material. To protect the insulation, it is usually covered with a closely-fitted outer layer of jacketing. Most jacketing is thin-gauge sheet metal pre-cut to cover the insulation with little or no gap. Joints are screwed together and may have pop-together seams. Most joints are specified to be caulked; many are specified but not actually caulked.

Currently, the sheet metal most commonly used for insulation jacketing is aluminum; stainless steel is also used, particularly where a corrosive environment is expected outside the insulated pipe or vessel. Two-sides galvanized and aluminized carbon steel have been used in the past for jacketing, usually with poor results. The galvanizing or aluminizing fails quickly, and the sheet metal corrodes; screw holes and untreated cut edges start rusting almost immediately after installation. Aluminum is usually no more expensive, easier to work with and much more durable, although even aluminum can’t always hold up to a refinery or chemical plant’s internal chemical fume and splash environment.

Fig. 4: Plant environment and acidic product leakage have eaten away the aluminum jacketing on this vessel—a clear indicator of moisture-saturated insulation.

Installed-in-place fiberglass reinforced polyester is an alternative to sheet metal jacketing, and has found limited use in the petroleum industry. Although it is seamless and more durable than sheet metal, the jacketing has to be sawed or ground open to be removed, and thus is not frequently used. Flexible thin plastic, electro-sealed at seams, is used on piping where mechanical damage is not expected, and precast rigid plastic jacketing is sometimes used for moderate temperature, clean-environment service where mechanical damage is not a factor.

Along with the damage from normal environmental exposure and a refinery’s much worse micro-climate, insulation jacketing also suffers from the damages caused by careless or unthinking humans, or by the hurried need to fix one thing without considering potential damage to others. Whether an insulated pipe run or vessel is used as an impromptu ladder, stairway, crosswalk or tool testing area (think hammer drops or large adjustable wrenches) or for a scaffolding extension when the original repair scaffold is just a bit short, the thin sheet metal jacketing and the brittle crushable insulation underneath suffer and do not recover.

Sheet metal jacketing is made up of hundreds, sometimes thousands of precut, preformed pieces, which fit together well when first installed. All those joints may actually seal against water entry when first installed; but they leak like a sieve after having been walked over, beaten on or otherwise abused and cannot be easily repaired once they are deformed.

ANTICIPATING PROBLEMS

The main cause of corrosion under insulation is water ingress through breaks in the outer jacketing. Ingress is then followed by absorption and release of water by the insulation material, and eventual attack and failure of the CUI coating due to the presence in the water of chemicals from the refinery or chemical plant environment or from the insulation material. Once the CUI coating breaks down, the pipe or vessel steel (carbon or stainless) starts to corrode from the outside inward. If the stored or carried product in the insulated pipe or vessel has water, contaminant or other corrosive agents, and if the vessel or pipe interior is not lined or is incompletely lined, the wall steel will start to corrode from the inside outward. Both these events cause loss of wall thickness in the pipe or vessel. If the two areas of corrosion coincide, wall thickness loss can occur very quickly and may precipitate a leak or blowout.

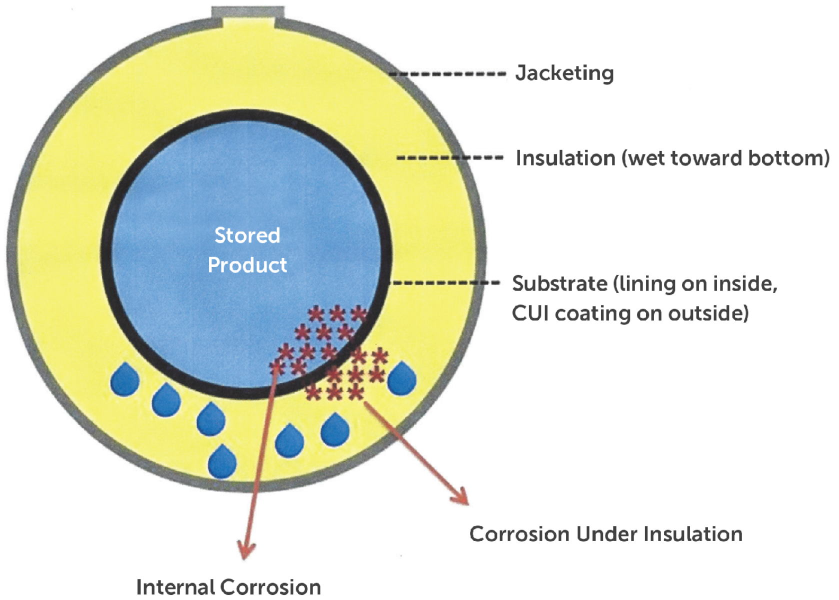

Fig. 5: Internal corrosion and CUI occur in the same area, accelerating wall thickness loss.

Most of the “problems” referenced in this article have come from successful, safe, well-maintained refineries and chemical plants owned by major global oil and chemical companies. A typical large refinery will have about a thousand vessels, most of them insulated, and several hundred miles of insulated piping. Removing and replacing an insulation system; stripping jacketing and insulation, abrasive blasting the steel, reapplying CUI coating and insulation material and then re-jacketing the insulation is a major, time-consuming and expensive process. Even just regularly inspecting the exteriors of all the insulated vessels and piping requires major investment of time and money. Not inspecting insulated equipment can have results ranging from minor leaks to disastrous events. In most cases, an operating unit must be shut in while replacing the insulation system, so there can be a double loss—the cost of the project, and loss of production during the shutdown from the unit being repaired, or possibly from a whole processing train to which the repaired unit is essential.

Refinery insulation systems are normally expected to last 15 to 18 years before replacement, but no one really knows the condition of all that steel under all that insulation. The exterior of the jacketing gives some clues, but is not 100% reliable and some jacketing and insulation removal are always required. Well-run refineries and chemical plants use a system called risk-based inspection to monitor the condition of insulated steel, and to try and predict areas of excessive corrosion before they cause problems and require unplanned major repairs.

Risk Assessment Matrix Chart

CONSEQUENCES OF AN EVENT					INCREASING LIKELIHOOD OF AN EVENT				
SEVERITY	PEOPLE	DAMAGE TO ASSETS	EFFECT ON ENVIRONMENT	IMPACT ON REPUTATION	A Has never been heard of in the industry	B Has been heard of in the industry	C Happened to us or happens more than once a year in the industry	D Happened at this site or more than once a year in our company	E Happened more than once a year at this site
0	No Injury	None	None	None					
1	Slight Injury	Slight	Slight	Slight					
2	Minor Injury	Minor	Minor	Minor					
3	Major Injury	Moderate	Moderate	Moderate					
4	<3 Deaths	Major	Major	Major					
5	>3 Deaths	Massive	Massive	Massive					

Fig. 6: This is a simplified chart for evaluating pipe and vessels in an RBI program. Greater severity and a higher likelihood of an event (see red field) require closer and more frequent inspection. *Original chart courtesy of Shell EP Americas, New Orleans, LA*

To set up an RBI program, the facility is inspected, and every insulated vessel and pipe is rated for its current condition, for the severity of problems its perforation or failure would cause, and for its past history (if any) of CUI-related problems. After the inspection and evaluation, small critical areas are designated, and at scheduled intervals, the jacketing and insulation are removed in these small areas, and the exposed CUI coating and steel are rated. If the corrosion found (there always is some!) is as expected, the exposed small area is reinsulated and rejacketed until the next scheduled RBI inspection. If more than the expected corrosion is found, additional surrounding or related areas are exposed, to try and find a cause, and additional maintenance time and money are scheduled to repair the problem once it is found. If less than expected corrosion is found, the same process is followed, assuming that corrosion elsewhere in the system is protecting the better-than-expected area.

Until recently, all RBI inspections required removing jacketing and insulation in the areas scheduled to be inspected. Recent developments in electronics now allow a wall thickness sensor to be buried under the insulation and jacketing. The sensor "reports" the wall thickness on its small measuring area at scheduled intervals, or on request, through the intact insulation and jacketing.

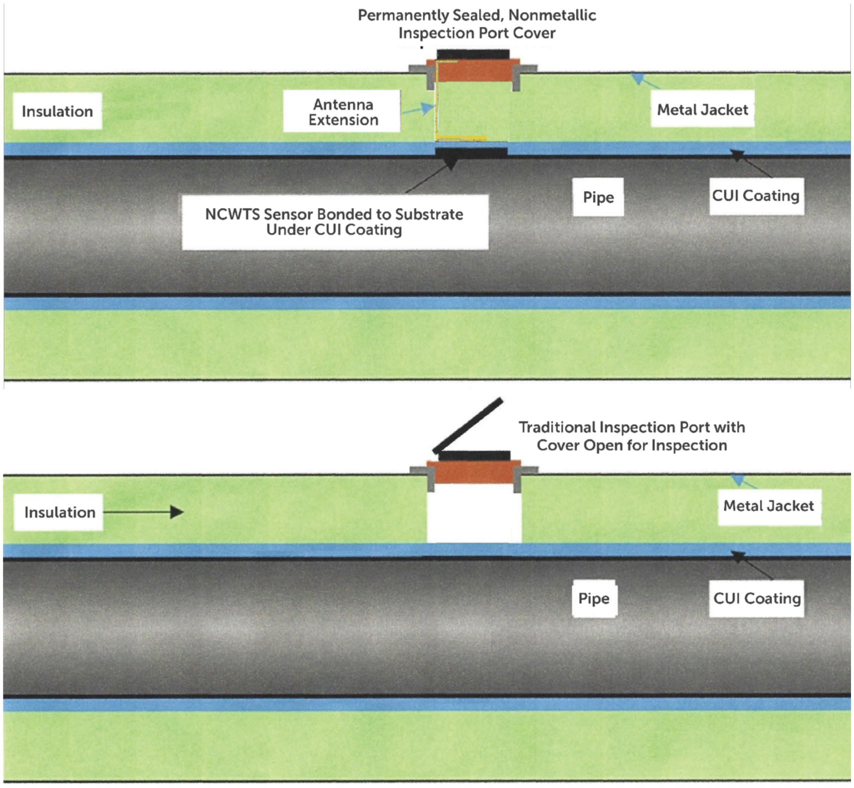

Fig. 7: This diagram shows a non-contact wall thickness sensor, which allows monitoring of wall thickness without having to remove insulation and jacketing.

Limitations at present are that the sensor only tracks a very small area of steel, and can only report total wall thickness, not whether the loss is from inside out, or CUI from outside inward, and it cannot report on the condition of steel and CUI coating around the area it measures for wall thickness. But now, CUI inspectors do not need to remove jacketing and insulation at scheduled intervals if wall thickness measurements have not changed over time since the last scheduled inspection of the same spot. The time and cost savings more than offset the cost of the electronics and computer setup required for this new, better RBI process.

ABOUT THE AUTHOR

Peter Bock is a petrochemical coatings, insulation and corrosion under insulation specialist based in Houston. He has more than 43 years of corrosion-control experience worldwide and has taught annual courses on CUI for over a decade. Bock is a NACE-certified Coating Inspector (Level III), is active in industry organizations, has been widely published in JPCL and other publications and has presented numerous papers at industry conferences. He is past chairman of the NACE Central Area Board of Trustees and a past JPCL contributing editor, as well as a JPCL Readers' Choice Award recipient and the recipient of two JPCL Editor's Awards. He holds degrees in business science from Tulane University and the University of Northern Colorado and currently owns Performance Polymers Americas, LLC, a specification, inspection and consulting firm specializing in third-generation inorganic coatings and spray-on insulation.