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VOLUME 36, NUMBER 3 THE VOICE OF SSPC MARCH 2019

FEATURES

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Periodical class postage at Pittsburgh, PA and additional mailing offices. The Journal of Protective Coatings & Linings (ISSN 8755-1985) is published monthly by Technology Publishing Company in cooperation with the SSPC (877-281-7772). Copies of articles are available from the UMI Article Clearinghouse, University Microfilms International, 300 North Zeeb Road, Box 91, Ann Arbor, MI 48106. FOR SUBSCRIPTIONS CONTACT US AT: Journal of Protective Coatings and Linings, 1501 Reedsdale St., Ste. 2008, Pittsburgh PA 15233-2341; Tel: 1-800-837-8303 (toll free); 412-431-8300 (direct); Fax: 412-431-5428; email: subscriptions@paintsquare.com. Subscription Rates: North America $90 per year; Rest of World $120 per year. Single issue $10.00. POSTMASTER: send address changes to Journal of Protective Coatings and Linings, 1501 Reedsdale St., Ste. 2008, Pittsburgh PA 15233-2341.

PAINT SQUARE
Printed in the USA / www.paintsquare.com

COATINGS+ 2019 AWARDS: TOP PEOPLE, PAPERS & PROJECTS

The first full day of Coatings+ 2019, SSPC's yearly conference and exhibition at Disney's Coronado Springs Resort in Orlando, featured the annual awards luncheon honoring the top people, papers and projects from the protective coatings industry over the past year.

The ceremony opened in the Coronado ballroom with remarks on some of SSPC's ongoing initiatives from SSPC President Garry Manous, Executive Director Bill Worms, Business Development Specialist Bob McMurdy and Director of Technology and Communications Michael Kline.

Heavy hearts loomed over the proceedings after the sudden passing of longtime SSPC staff member Monica Pierce in January. Worms offered a tribute to whom SSPC employees called "the life of the party" and encouraged conference attendees to honor Pierce's memory by enjoying the week to the fullest.

As part of SSPC's ongoing charitable ventures, Worms also presented a check totaling $2,000 to the Adult Literacy League at the ceremony. Founded in 1968, the ALL advocates on behalf of adult and family literacy, aiming to educate adults throughout Central Florida to become self-sufficient members of society.

INDIVIDUAL AWARDS

(L-R): SSPC President Garry Manous and Bill Shoup.
Photos courtesy of SSPC.

The **Honorary Life Member** is given for extraordinary contribution and long-term activity on behalf of SSPC. To become an Honorary Life Member, an individual must be nominated by an SSPC Board member and approved by two-thirds of the Board. Only one Honorary Life Membership is awarded each year. This year's Honorary Life Member was Bill Shoup, SSPC's former executive director from 1999 to 2015. Shoup addressed the crowd, sharing some highlights from his 16 years with SSPC and remarking that although he took over SSPC at what he termed "a rough time," he was proud that he "left it better than [he] found it." He also offered his own fond memories of Pierce, his co-worker and friend of many years.

The **John D. Keane Award of Merit**, named after SSPC's executive director from 1957 to 1984, recognizes outstanding leadership and significant contribution to the development of the protective coatings industry and to SSPC. Mark Schultz of The Sherwin-Williams Company was honored with this year's Keane award. A 25-year industry veteran with experience in the railroad, shipyard and military sectors, Schultz's willingness to teach and foster development and success for others in the industry were lauded by award presenter Doni Riddle of Sherwin-Williams.

(L-R): Manous and Mark Schultz.

(L-R): Juan Caballero and Manous.

(L-R): Manous and Dejin Feng.

The **Richard W. Drisko Coatings Education Award** is given for significant development and dissemination of educational material and technical information related to protective coatings and their application. This year, there were two recipients: Juan Caballero of Naval & Industrial Solutions, and Dejin Feng of Rader Coating Technology—Shanghai Co. Ltd. Caballero, the first SSPC-certified Master Coating Inspector (MCI) in Latin America, co-founded the SSPC Panama chapter, sits on the SSPC Board of Governors and instructs Spanish-language SSPC courses, while Feng was credited with establishing the Protective Coatings Inspector

(L-R): Manous, Greg Roby and Brad Wilder.

(PCI) Training Program in China and successfully re-organizing the China chapter and holding its first-ever event, GreenCOAT China, in October of 2018.

The **Technical Achievement Award** recognizes outstanding service, leadership and contribution to the SSPC technical committees. Brad Wilder of Intech Contracting LLC, and Greg Roby of Stantec were the 2019 recipients. Presenter Henry Arato of SSPC applauded Wilder and Roby for their combined work on SSPC's QP 1 and QP 2 committees, including ironing out the specific language and clearly explaining the rationale behind recent revisions to the membership.

The **Women in Coatings Impact Award**, established in 2014, recognizes women in the coatings industry who have helped create a positive impact on the culture of the industry. This year's

(L-R): Manous and Judie Blakey.

award winner was Judie Blakey, a retired consultant with over 40 years of shipyard expertise. Blakey's career started at General Dynamics-NASSCO and progressed to her own consultancy and participation in the National Shipbuilding Research Program (NSRP), and presenter Robert Cloutier of Bath Iron Works credited her for bringing standardization and improvement to shipyard blasting and painting practices in the U.S. and abroad.

(L-R): Kevin Keith and Manous.

The **President's Lecture Series Award** is presented to papers handpicked by the SSPC President and chosen for the reflection of the coatings industry and profession. This year's award-winning paper was "Putting the Pieces Together: Integrating Steel Repairs with Bridge Painting Projects," by Kevin Keith of the LIRO Group. Keith's paper was adapted as a feature in the January 2019 *JPCL*.

SSPC also presented **Outstanding Chapter Awards** to the Gulf Coast and Philippines Chapters, recognizing each for their dedication to the industry and SSPC in their respective regions.

JPCL AWARDS

For the second year, JPCL let its readers choose the top articles from the past year via online survey. The following authors were presented with JPCL Readers' Choice Awards for their work.

- Case History: "Troubled Bridge Over Salt Water," by Michael Woodward, Carboline Company.
- Failure Analysis: "The Sky Is Falling! Or Is It Paint Chips? Failure of a Dry-Fall Coating Applied to the Interior of Previously Painted Metal Decking," by Richard Burgess, KTA-Tator Inc.
- Process: "Power-Tool-Cleaned Surfaces: New Insights into Surface Profile Measurement," by Jody Wenzel, DeFelsko Corp.
- Proficiency: "The Need for an Independent Third-Party Coating Inspector," by Tim Bauman, The Sherwin-Williams Company.
- Safety: "Hazardous Metals and Materials: Paint and Waste Sampling Analysis," by Alison Kaelin, ABKaelin LLC.
- Technology: "Three-Coat & Epoxy Mastic Bridge Coating Systems in Adverse Environments," by Saiada Fuadi Fancy, Md. Ahsan Sabbir and Kingsley Lau, Florida International University, and Dale DeFord, Florida DOT.

The JPCL Editors' Choice Award was presented to the top article chosen by the JPCL editors. Peter Bock of Performance Polymers LLC and James C. Reynolds of Performance Polymers B.V. were awarded for their paper, "From Pig Fat to Polysiloxane."

STRUCTURE AWARDS

In addition to the top people and papers, SSPC also presented the annual Structure Awards, honoring outstanding coatings projects from the past year. The winning projects follow; each project will be featured in-depth in future issues of JPCL.

- Charles G. Munger Award: Luza Street Elevated Storage Tank (Bryan, Texas).
- E. Crone Knoy Award: USS ESSEX (LHD 2) (San Diego, California).
- Eric S. Kline Award: EnBW Hohe See (North Sea, Germany).
- George Campbell Award: Walt Whitman Bridge (Philadelphia/Gloucester, New Jersey).
- Military Coatings Award of Excellence: USS George Washington (CVN 73) Aircraft Carrier (Newport News, Virginia).
- Coatings Industry Spirit Award: Elevated Water Storage Tank (Oak Grove, Kentucky).
- William Johnson Award: Anaerobic Digesters & Storage Tank Coatings (Lincoln, Nebraska).

Houston Coating Society Preps for Painters' Competition, Trade Show

The Coating Society of the Houston Area is gearing up for two of its popular yearly events — the 30th annual Painters' Competition and the 2019 CSHA Trade Show.

The Painters' Competition will be held on March 30 at the Pasadena Fairgrounds in Pasadena, Texas. Currently, the Coating Society is looking for teams of three — composed of a foreman, craftsman and helper — to show off their painting skills by competing in the event. Entry is free; paint, panel and air will all be supplied, while the team or its sponsor must supply the rest of the equipment needed. According to an emailed announcement, the first-place winner will receive $900 and a free SSPC or NACE International training course.

Other activities for the family will include games, door prizes, face painting, food and a new Easter egg hunt. Festivities start at 7:30 a.m. and end at 3:30 p.m.; the competition will begin at 9:00 a.m.

On April 12, the Society will also hold its annual trade show at the Pasadena Convention Center's Campbell Hall on April 12. This unique get-together will bring together Houston-area painters and out-of-town industry professionals alike to take in the show's 70-plus exhibitors, technical session, awards ceremony and crawfish dinner.

The show will kick off at 10:00 a.m. with the opening of the exhibit, which will feature live equipment demonstrations throughout the day. At 3:00 p.m., Michael Selmach of Saulsbury Industries will present, "Fireproofing for Refineries and Petrochemical Facilities." The day will close with the crawfish boil and awards ceremony at 6:00 p.m. Attendees can also register for NACE International's Corrosion Demo Day from 12:00 noon to 5:00 p.m.

For more information on the CSHA and its upcoming events, visit www.coatingsocietyofhouston.org.

AkzoNobel Releases Q4, 2018 Numbers

Global coatings manufacturer AkzoNobel released its fourth-quarter and end-of-year financial reports on Feb. 13, indicating a 1-percent increase in revenue for Q4, and a 4-percent decrease in revenue for the full year, though there was a 1-percent increase in constant currencies.

In early October, AkzoNobel completed the sale of its $2.5 billion Specialty Chemicals business to The Carlyle Group and Singapore's sovereign wealth fund GIC, returning 6.5 billion euros to shareholders. Net profit on the sale was 5.8 billion euros.

The return on sales (ROS) for the Performance Coatings' fourth quarter was up at 10.9 percent, with a price/mix of 11 percent driven by pricing initiatives. Marine and Protective Coatings Revenue was up 5 percent in constant currencies. Profitability has largely been attributed to cost savings and price conditions. Powder Coatings also saw similar gains, clocking in a 6-percent increase in constant currencies.

The segment's revenue was up 2 percent and up 4 percent in constant currencies. Adjusted operating income saw a 20-million-euro increase at 153 million euros, over 2017's 133 million euros, which was largely driven by pricing initiatives and cost control.

For AkzoNobel's 2018, revenue was 4 percent lower, though up 1 percent in constant currencies. Adjusted operating income totaled 798 million euros, down from 2017's 905 million euros, which was impacted by adverse currencies, higher raw material costs and lower volumes.

For Performance Coatings, revenue was 3 percent lower, though there was also a 1-percent increase in constant currencies. Adjusted operating income clocked in at 629 million euros, down from last year's 669 million euros, which was largely attributed to adverse currencies, higher raw material costs and lower volumes.

Phase one of the company's "transformation to create a fit-for-purpose organization" delivered on the planned 110-million-euro savings for 2018. Moving forward, AkzoNobel aims to deliver the next 200 million euros in cost savings by 2020.


Photo: Google Maps

In Response to, "IL Aldermen Decline to Repaint Bridge" (PaintSquare News, Feb. 25)

After city aldermen in Evanston, Ill., recently declined to paint a rusted, lead-paint-coated rail bridge that belongs to the Union Pacific railroad company, PaintSquare commenters lamented the continued trend of passing the buck and putting off much-needed infrastructure maintenance.

Stephen Gressel:
"They should test what's left of the paint for lead and when they find lead in it, sue the railroad for letting the paint flake off and contaminate the surrounding area."

Mark Bowen:
"Unfortunately, railroads have more Philadelphia lawyers than you can deal with."

PAINTSQUARE NEWS TOP 10

paintsquare.com/news, Feb. 4 - March 3

1. **AkzoNobel Releases Q4, 2018 Numbers**
2. **EU Titanium Dioxide Decision Takes Another Step**
3. **Judge Blocks Work on Keystone XL Pipeline**
4. **ASTM Announces New Test Method for Corrosion**
5. **WY Utility's First Wind Farm Faces Replacement**
6. **Falling Concrete Temporarily Closes CA Bridge**
7. **Australia Bridge to be Repainted for the First Time**
8. **IL Aldermen Decline to Repaint Bridge**
9. **Sika Could Acquire BASF Construction Segment**
10. **Government Aims to Terminate CA Rail Funding**

Problem Solving Forum

paintsquare.com/psf

Your field surface preparation requires SSPC-SP 10 and your field bolting uses hot-dip galvanized bolts. What surface preparation do you require/allow on and around the bolts?


Getty Images / mdurinik

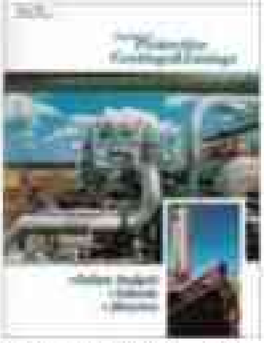
Jonathan Rausch:
"Make sure the steel is primed before assembly, then topcoat after final assembly. With the nuts and bolts being galvanized and painted, that should give you a decent lifespan, in my opinion."

Michael Beitzel:
"It is assumed [that] a zinc primer is to be used and should be applied to bolts and around the bolts. Solvent-clean to remove lubricant from bolts and any oil or other residue from bolting operations. If the field around the bolts has been blast-cleaned and primed, a zinc-phosphate treatment solution could be used on the galvanized bolts, or comply with ASTM 6386, which allows for sweep-blasting, surface sanding or power-tool cleaning such as bristle-blasting. If the field around the bolts is unprimed, it should be blast-cleaned prior to bolt installation, which would be followed by the above cleaning of the bolts. If the field is unblasted prior to bolt installation, solvent-clean bolts and field and blast to SSPC-SP 10, avoiding direct blasting of bolts and prime bolts."

THIS MONTH IN ...

1989

One of *JPCL*'s most prolific past authors, the late Mark Schilling, penned, "Caveat Emptor: Understanding Coating Failures in Petrochemical Plants," which presented case histories to demonstrate proper and improper coating fundamentals and offer guidance in avoiding failures in chemical and petrochemical plants.



1992

The late Eric S. Kline was renowned for coming up with innovative coatings solutions to age-old corrosion problems, and his article, "Beneficial Procrastination: Delaying Lead Paint Removal Projects by Upgrading the Coating System," co-authored with Bill Corbett of KTA-Tator, Inc., described state-of-the-art alternatives to total removal of lead-based paint.

2002

In his article, "Coating Selection and Important Properties of Coatings for Concrete," Randy Nixon of Corrosion Probe, Inc., took a wide-angle look at the world of concrete coatings, outlining the reasons concrete is coated and addressing important properties to consider when selecting coatings to meet varying exposure conditions.

2010

As the push for renewable energy began (and continues today), coating technology for this infrastructure became a topic of interest for the *JPCL* readership. "Corrosion Protection of Offshore Wind Turbines — A Challenge for the Steel Builder and Paint Applicator," by Karsten Mühlberg of Hempel stressed the importance of protecting offshore wind turbines, coating systems on the market and the expenses related to repairing a premature failure offshore.

Corrosion Protection of Cargo Tanks in Crude Oil Carriers: Update on IMO Regulations

BY BRIAN GOLDIE, JPCL

As a result of incidents of structural failure of vessels due to corrosion causing loss of life, IMO passed amendments to the SOLAS (Safety of Life at Sea) regulation II-1/3-11 requiring that adequate corrosion prevention measures be taken by owners. The first area of a vessel deemed to cause potential problems was the dedicated seawater ballast tanks, and guidelines were proposed for improving the types of coatings used for corrosion protection. The guidelines were superseded by the Performance Standard for Protective Coatings (PSPC) regulation for seawater ballast tanks mandating the degree of surface preparation and type of coating used at newbuilding. IMO has now developed requirements for corrosion protection of cargo tanks in crude oil carriers — MSC.291(87), part of which is a new PSPC. This legislation covers new crude oil tankers of 5,000 dwt or greater. The extension of the PSPC to crude oil carriers coincides with the adoption by the Maritime Safety Committee (MSC) of IMO, at its 87th session in May 2010, of a major change in the way international standards for ship construction are to be determined and implemented in the future, i.e., as "goal-based standards." The adoption of these standards for oil tankers (and bulk carriers) by the MSC means that newly constructed vessels of these types will have to comply with structural standards conforming to functional requirements developed and agreed to by the Committee. Therefore, for the first time in its history, IMO will be setting standards for ship construction. The MSC also adopted guidelines that give the Organization a role in verifying conformity with SOLAS requirements. Since the beginning of the millennium, governments and international organizations have been pressing for IMO to play a larger role in determining the structural standards to which new ships are built. The reasons for IMO's larger role are that ships should be designed and constructed for a specified design life, and that if properly operated and maintained, they should remain safe and environmentally friendly throughout that period.

Just as the concept of "goal-based ship construction standards" was introduced in IMO November 2002, the pressure to develop a "standard" for corrosion protection of crude oil tanks also goes back to the early 2000s. Both of these measures should markedly increase the safety of double-skinned crude oil carriers.

The need for a standard for coating crude oil tanks goes back to 2004, when a working group was set up to look at any potential problems arising with double-hull tankers in the future. Several recommendations were made, including the need to coat the under deckhead and tank bottoms to reduce corrosion risk. A performance standard for coatings was also recommended. Following this, the International Association of Classification Societies (IACS) set up a joint working group with representatives from several industry bodies, including INTERTANKO, tasked with developing such a standard. The resulting regulations, the Performance Standard for Protective Coatings for Cargo Oil Tanks of crude oil carriers (PSPC COT), were incorporated into the Corrosion Protection of Cargo Oil Tanks of Crude Oil Tankers, accepted by IMO and adopted by the MSC 87 meeting in May 2010 (Resolution MSC.291). This article reviews the PSPC COT.

CORROSION PROTECTION OF CARGO OIL TANKS

Changes in designs and building methods of ships over the past decades, together with increased environmental regulations, have not necessarily lowered the impact of corrosion. Vessels are also getting larger and more complex, resulting in increased surface areas, often difficult to access for application, inspection and maintenance of protective coatings. These new corrosion protection regulations are aimed at improving the

Editor's Note: This year marks the 35th anniversary of the publication of JPCL, the definitive source of technology and information about protective and marine coatings. To celebrate, JPCL will be highlighting archived content — updating previously published technical articles throughout the year and looking back on past practices and technologies.

This article initially ran in the August 2010 issue and has been updated by the original author along with Dr. Raouf Kattan of Safinah Group for publication in this issue.

corrosion protection and thus maintaining the structural integrity of crude oil tanks. In general, the areas to receive better protection now are the under deck tank top (ullage space) and the cargo tank bottoms, or, more specifically, the following (Figs. 1 and 2).

- Deckhead and structure, including brackets connecting to longitudinal and transverse bulkheads.
- Longitudinal and transverse bulkheads to the uppermost means of access level.
- Areas with no uppermost means of access (the coating must extend to 10 percent of the tank's height at the center line but need not extend more than 3 m down from the deckhead).
- Flat inner bottom and structure to height of 0.3 m above inner bottom.

According to the regulations, the requirements can be achieved by different means. The three options are by use of coatings, by alternative means or by exemption.

Fig. 1: Loaded—corrosion potential from thermal cycling. Photo courtesy of International Paint.

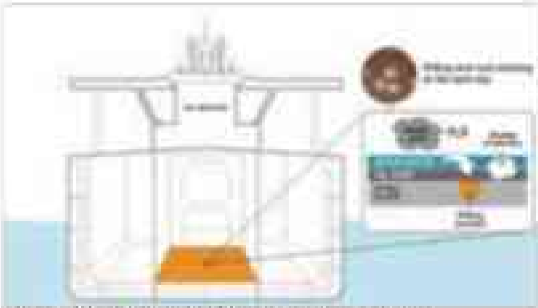


Fig. 2: Unloaded—corrosion potential from pitting in tank bottom. Photo courtesy of International Paint.

COATINGS

This option requires the coating of new tanks in accordance with the PSPC for Cargo Oil Tanks of Crude Oil Tankers (PSPC COT), Resolution, MSC 288(87). The coatings should have a useful life of 15 years in "good" condition. The coating to be used should be tested according to Annex 1 of this Resolution, or its suitability should have been established by at least five years of in-service exposure, with a final rating of its condition of at least "good." Compatibility of the coating with any pre-fabrication should be demonstrated and recorded on the system Type Approval Certificate. The conditions laid-out in the PSPC COT are the same as those in the ballast tank PSPC: control on application; inspection by qualified coating inspectors; data collection requirements and inclusion of the information on the crude tank coating system in the Coating Technical File (CTF).

One of the coating testing protocols, and the most controversial, is that of crude oil immersion testing. The composition of crude oil varies markedly with the source, so it would be impossible to select just one to test coating compatibility. The compromise was that a "model" crude would be used to reflect the different components in a crude oil. However, the naphthenic acid content of the "model" selected has a relativity high acid value of ~2.5 mg KOH/g (the amount of potassium hydroxide [mg] required to neutralize one gram of oil) and the majority of current epoxy cargo tank coatings used could not meet this requirement. A Type Approval Certificate could, however, be obtained on the basis of the coatings' good performance in practice, but any new coating introduced would have to meet the new protocols.

Since the introduction of the PSPC COT, paint manufacturers have been carrying out their own testing on new products before having them tested externally and Type approved. Earlier this year, one manufacturer announced that its principal anticorrosive primers and shop primers had successfully passed the very demanding IMO PSPC COT laboratory tests in accordance with the IMO MSC 288(87) SOLAS regulations for cargo oil tankers. The products passing laboratory tests include key ones from the company's epoxy and primer lines for marine application. Approved laboratories carrying out the testing included COT bv, based in the Netherlands. COT bv was the first laboratory in the world with specific Lloyd's Register approval to carry out testing in accordance with the IMO MSC.288(87) regulations for Cargo Oil Tankers. Class Society Type Approval Certifications were issued in due course.

Proof that an epoxy cargo tank coating can have the required performance to meet this standard can be seen from an inspection of the cargo oil tanks of the *Samco Raven* after 15 years. This 301,653 dwt crude oil tanker had the upper and lower areas of her cargo oil tanks coated with an abrasion-resistant, aluminum pure epoxy coating immediately after delivery in June 1996. At her third special survey and planned maintenance at Yiu Lian Dockyard (Shekou), China in 2011, nine of her 15 cargo oil tanks were assessed and the coating condition was rated as excellent throughout. In addition, the coating manufacturer reported that very little breakdown was observed on edges, weld seams, cutouts and scallops throughout the tanks, with only a small number of minor, isolated spots of corrosion present. No breakdown was visible directly above, at or below the cargo load lines, and the coating was in excellent condition in areas surrounding bell-mouths and on sharp edges around cargo wells.

Another coating manufacturer has also announced that its protective coating systems, including a range of epoxy products and shop primers for marine applications, have passed the laboratory tests required by the IMO performance standard for PSPC COT. The coatings were applied on panels and subjected to a 90-day, gas-tight chamber test, which simulates the cargo tank environment in loaded and unloaded condition, and a 180-day immersion test which simulates conditions in a loaded crude oil tank. The test panels were then examined for blisters, rust and other defects.

ALTERNATIVE MEANS

A second method of meeting the regulation allows cargo tanks to be protected by what has been defined as "alternative means." An example of this would be the use of corrosion-resistant steel that could meet the required structural integrity for at least 25 years according to MSC 289(87), Performance Standard for Alternative Means of Corrosion Protection for Cargo Oil Tanks of Oil Tankers.

EXEMPTION

There is also a third option contained in the regulation: a vessel's flag state can choose to exempt a crude oil carrier from the requirements if the vessel is solely for carrying cargoes, or performs cargo handling operations (such as floating production, storage and offloading [FPSO] units) with cargoes that do not cause corrosion. What these cargoes are still has to be decided and agreed upon by IMO.

CONCLUSIONS

The PSPC COT regulation is obviously going to put more pressure on owners, shipyards and coating suppliers for what they need to do to be ready by January 2013 to meet the requirements, especially in the current economic climate.

UPDATE

While there is no doubt that the introduction of these standards has been a positive step toward improving vessel safety, there are still many issues that remain for discussion, and several initiatives to consider updating or revising to remove technical inaccuracies and ambiguities, as well as allowing them to better encourage newer, alternative solutions.

Thus, the vessels to which this regulation has been applied are now coming up to their five years in service period, and so the first third-party inspections of coating performance will start to be undertaken. As with the PSPC for ballast tanks, the industry seems to have missed a real chance to collect and collate data on coating performance in service, after the introduction of the two PSPC regulations.

The removal of the PSPC requirements from the IACS common structural rules, leaves these SOLAS requirements as purely a flag state issue.

Sadly, few statistics have been made available (if any have been even collected at all) to enable a broader and more thorough assessment of the exact impact of these measures.

It can be argued that for the COT, it is still too early to draw any conclusions, but it would be interesting to know if any meaningful in-service data is being collected to understand how the coatings are performing and therefore how indicative the laboratory test results are in relation to real-life service, as this may provide an opportunity to inform future standards and testing regimes.

While there is no doubt that the introduction of these standards has done much to raise awareness of corrosion-related issues, it seems that an opportunity to gather big data and assess in-service coating performance has likely been missed.

Electronic Inspection of a Field Painting Project Part 2: Assessing Painter Skills

BY CORY ALLEN, VULCAN PAINTERS, INC.

PROJECT REVIEW

Coating inspection has been made more efficient and effective through use of electronic equipment, which can collect, store, transmit and populate inspection reports with data taken directly from the field. Part I of this article explained how the data captured electronically during a field painting project was translated to assess dry-film thickness ranges and other application performance characteristics. This second part will continue to expound upon that electronically collected data to uncover more important information for coating applicators and inspectors.

For the project, a certified inspector monitored the cleaning and coating of equipment in a municipal wastewater treatment facility, performed by an SSPC-QP1- and QP 2-certified painting contractor. The scope of work required abrasive blast-cleaning to remove existing coatings for both immersed and non-immersed steel and concrete surfaces, followed by recoating with high-performance industrial coating systems for 14 clarifiers. The project also included removal of lead-based paint and recoating of a methane gas sphere.

The field inspector found that the specified method to measure film thickness (SSPC-PA 2) provided unacceptable sampling error. As a result, sampling frequency had to be increased to reduce the percent margin of error. With the use of an electronic dry-film thickness gauge, even the increased numbers of dry-film thickness inspection measurements were taken relatively quickly and recorded into memory.

The precision profiles from statistical analysis of data collected from applications showed that the distribution of dry-film thickness was affected by common causes consisting of painter skills, the shape of the part painted, the method of application and the material applied.

INFLUENCE OF PAINTERS' SKILLS ON σ

The goal of an industrial coating applicator is to apply the coating at a target wet-film thickness to obtain a uniform finish at the specified dry-film thickness.

During the work, a blind experiment was conducted to determine the influence of painter skills on the standard deviation (σ) of film thickness. The experiment consisted of roller application of the three-coat immersion coating system by two painters on three primary clarifiers. Two journeyman painters, Painter A and Painter B, roller-applied half of the outside diameter of each feedwell drum. As customary with industrial painting protocol, each painter only worked on the same half of each feedwell drum that he had previously painted, so that each half-side was painted only by that one painter.

Fig. 1: Measurement of dry-film thickness on feedwell.
Figures courtesy of the author.

After each application, the film thickness was measured by the same certified inspector who had taken measurements in Part I of this article using a Type II electronic gage (Fig. 1). Film thickness measurements were spaced approximately 24 inches (60.96 centimeters) apart on each of the two 235-square-foot (21.8-square-meter) feed well half-cylinder areas and taken from a rolling scaffold.

For the first feedwell (primary clarifier #6), there was a significant difference in the applied coating results. Figure 2 shows that Painter A achieved an average film-thickness (μ) of 7.18 mils (182.3 μm), which was close to the specified film thickness of 5-to-7 mils (127-to-177.8 μm), with a standard deviation (σ) of 3.03. However, Painter B was outside the film thickness range, with an average of 10.07 mils (255.7 μm) and a standard deviation of 4.6.

Table 1: Precision Profiles, σ: Painters Skills Comparison Chart — Film Thickness σ (1st Coat).

	1st Coat Primary Clarifier #6	1st Coat Primary Clarifier #4	1st Coat Primary Clarifier #3
Painter A	2.83	3.18	2.94
Painter B	4.40	3.28	3.34

The applications by Painter A and Painter B were followed for each of the three feed wells; primary clarifier #6 was painted first, then primary clarifier #4 and lastly primary clarifier #3. The results for σ recorded for the primer coat for each of the three feedwells are shown in the comparison chart in Table 1.

Painter A remained at the same skill level for each of the three feedwell primer coats, but Painter B progressively improved for each application of the primer. Film thicknesses for all three coats for each of the three feedwells were measured at the same frequency of 100 measurements spaced about 20 inches (50.8 centimeters) apart and recorded in separate batches. Batch data was categorized and the σ for final coating thickness is shown in the comparison chart in Table 2.

The total dry-film thickness was specified at 15-to-21 mils (381 to 533.4 μm). Film-thickness averages are shown in Table 3. The total film thickness of each coating system applied to these simple structures was within a few mils (25.4 μm). The σ values found for each of these painters' applications shows that Painter A could produce a more narrow thickness range using the

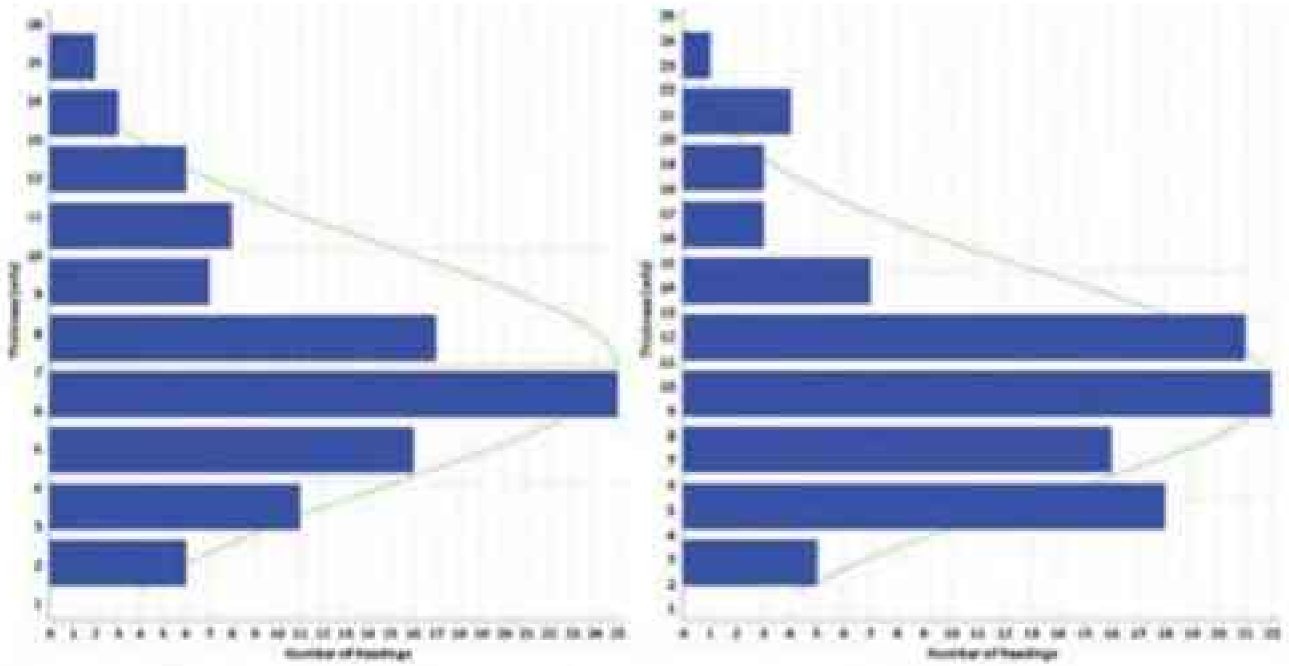


Fig 2: First coat by Painter A: σ = 3.03 and mode of 6.5 mils; Painter B: σ = 4.6 and mode = 9.5 mils. Acceptance criteria should be σ = 2.7 and mode +/- 0.5 mils from the specified average thickness of 6 mils.

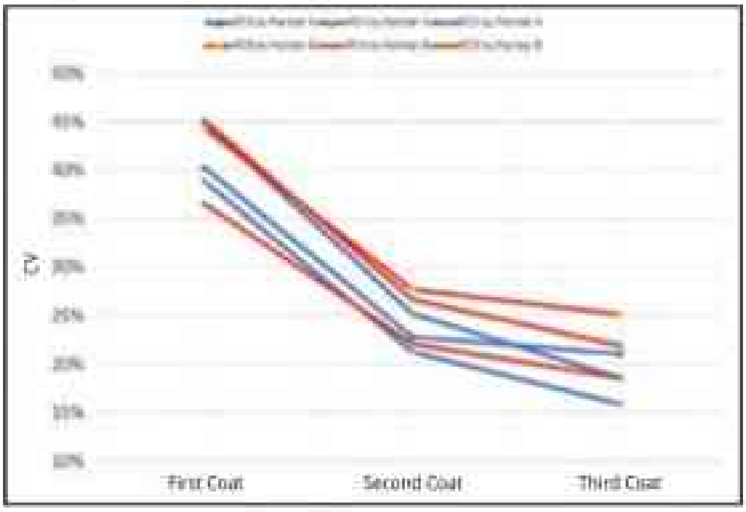


Fig. 3: Coefficient of variation (CV, %) for Painters A and B.

same tools and coating than Painter B could. Further, this experiment demonstrated that the use of the standard deviation as a criterion for a coating application could be an effective method for assessing skills.

Using the average standard deviation (σ) and the average film thicknesses (μ) the coefficient of variation (CV) can be calculated according to the following equation:

$$CV\% = (\sigma/\mu)100$$

The coefficient of variation takes in to account the average film thickness, which makes the results all the more significant (Fig. 3).

Two target scores were produced to illustrate this variation. The first scoring target (Fig. 4, p. 20) has an average of 7.3 points, and includes high point shots of 9.0 and 8.5. The second scoring target (Fig. 5, p. 20) has a nearly identical average score of 7.4, but the highest point shot is 8. Table 4 (p. 20) shows the scoring target analysis.

Table 2: Precision Profiles, σ: Painters Skills Comparison Chart — Film Thickness σ (3rd Coat).

	3rd Coat Primary Clarifier #6	3rd Coat Primary Clarifier #4	3rd Coat Primary Clarifier #3
Painter A	4.45	3.59	3.37
Painter B	5.84	4.61	3.80

Table 3: Painter Skills Comparison Chart — Film Thickness Averages.

	3rd Coat Primary Clarifier #6 mils (µm)	3rd Coat Primary Clarifier #4 mils (µm)	3rd Coat Primary Clarifier #3 mils (µm)
Painter A	21.05 (534.6)	20.93 (531.6)	21.14 (536.9)
Painter B	23.30 (590.8)	21.09 (535.6)	20.43 (518.9)

Since both scoring targets have the same average score, would those painters be equal in skill?

By calculating the standard deviation (σ) and the coefficient of variation (CV), it is evident that the second scoring target was more skilled due to less variation (Fig. 6, p. 20). There is a much tighter packing of shots, whereas the first scoring target has three times more variation, with a wide scoring range from 6.0 to 9.0.

INFLUENCE OF STRUCTURE SHAPE AND SIZE ON σ

Calculating the influence of film thickness on the precision profiles from Part I of this series, the common cause of variation due

Fig. 4: First target score; 10 shots with score mean (μ) = 7.3.

Fig. 5: Second target score; 10 shots with score mean (μ) = 7.4.

to application methods (brush and roller versus airless spray) and structure shape (simple or complex) is shown in Table 5.

The greatest variance was found for brush and roller application on the complex surfaces, such as rake arms and center column cages; the least variance was found in the airless spray on simple surfaces, such as the feedwells and center columns. Comparing these empirical variances to the theoretical variance for the painting manufacturer's product data sheet-specified film thickness using a theoretical normal distribution at $\sigma = 2.0$ and $\mu = 18.0$ mils produced an 11.0-percent coefficient of variation.

CONCLUSIONS

Statistical analysis of application data showed that the distribution of dry-film thickness was affected by common causes consisting of painter skills, the shape of the part painted, the method of application and the material applied. Measuring frequency should be dictated accordingly. For example, sampling frequency should be greater for applications with a high standard deviation, such as a complex shape painted with a brush or roller, than for applications with a low standard deviation, such as a simple shape painted via airless spray. For the first coat of brush and roll applications on complex structures ($\sigma = 2.8$), about 150 DFT measurements were taken for every 1,000 square feet; for the second coat ($\sigma = 4.1$), sampling frequency was doubled to 300 DFT

Table 4: Scoring Target Analysis.

	μ	σ	CV, %
1st Target (Fig. 4)	7.3	1.03	14.15
2nd Target (Fig. 5)	7.4	0.37	4.95

Table 5: Coefficient of Variation (CV, %) by Shape and Application Method.

	Brush & Roll			Airless Spray		
	1st Coat	2nd Coat	3rd Coat	1st Coat	2nd Coat	3rd Coat
Simple Shape (feed wells)	38.4%	26.0%	22.1%	23.7%	17.7%	14.7%
Complex Shape (rake arms)	45.5%	33.9%	31.2%	28.5%	25.7%	18.9%
Paint Manufacturer's Product Data Sheet (PDS)	11.0%	11.0%	11.0%	11.0%	11.0%	11.0%

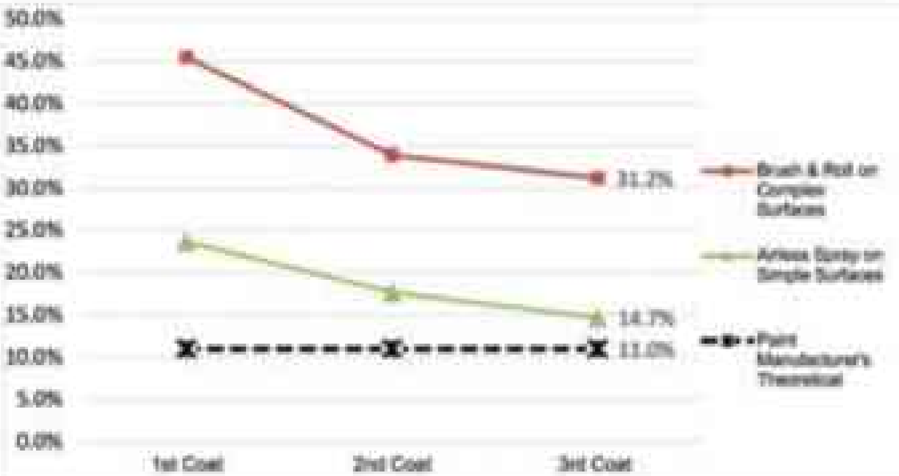


Fig. 6: Coefficient of variation (CV, %) by application method and paint manufacturer's PDS.

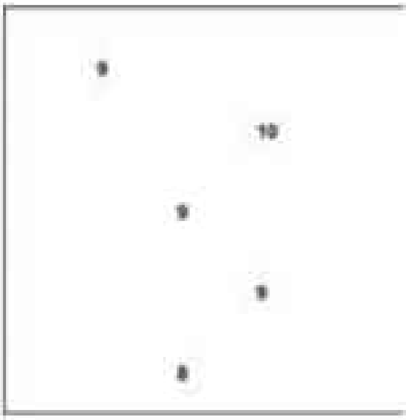


Fig. 7: Sampling frequency = one every 20 feet[2].

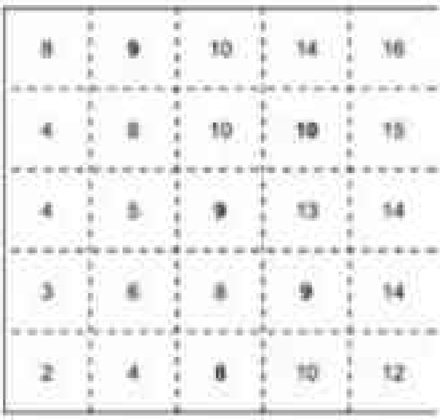


Fig. 8: Sampling frequency = one every 4 feet[2].

measurements; for the third coat (σ = 5.8), sampling frequency was doubled again to 600 DFT measurements.

Figures 7 and 8 illustrate this improved method. Figure 7 shows a 100-square-foot panel with five spot readings taken according to SSPC-PA 2. This sampling frequency is one spot measurement for every 20 square feet, or 0.06 percent of the total area. The average film thickness is 9.0 mils, the standard deviation is 0.71 and the coefficient of variation is 7.89 percent.

Figure 8 also shows a 100-square-foot panel, but with 25 spot measurements. Sampling frequency is one spot measurement for every 4 square feet, or 0.30 percent of the total area. The average film thickness is also 9.0 mils, but the standard deviation is much greater at 3.97 and the coefficient of variation is 44.11 percent.

By increasing the sampling frequency — for example, one spot reading for every 4 square feet, which is now a practical option with electronic instrumentation — one might discover that the painter applied lower thickness on the bottom of the panel and higher film thickness on the top right-corner. Inspection bias can be reduced by increasing the sampling frequency with the use of electronic instruments. Quality standards for painting applications are expected to become more specific and stringent.

In particular, painter skills will be scrutinized more closely. As the blind experiment demonstrated, the ability of painters to apply liquid paint in even passes with 50-percent overlaps to produce uniform dry film thickness were quantified as the standard deviation (σ) and coefficient of variation (CV).

In the future, this method may be used to assess painter skills, as well as for realistic expectations of uniform film-thickness ranges specified by industry standards, and not by the recommended film thicknesses on paint manufacturers' data sheets.

Not only were sampling error and operator bias reduced by using the electronic gauge and improving the sampling method, but analysis of the data collected electronically was able to provide some important details about the coating application during the project that may have been otherwise overlooked using traditional, manual inspection equipment.

ABOUT THE AUTHOR

Cory Allen serves as the director of quality systems for Vulcan Painters, Inc., administering the company's quality management system and its adherence to the SSPC QP and QS programs. He is a member of the American Society of Quality and is certified as a Quality Manager, Quality Auditor and Six Sigma Green Belt. He holds a Master's degree in polymer chemistry and a Bachelor's degree in chemistry from the University of Southern Mississippi.

PENNY-WISE OR POUND-FOOLISH?

HOLDING PRIMERS FOR SOLVENT-FREE EPOXY TANK LININGS

BY MIKE O'DONOGHUE, PH.D. AND VIJAY DATTA, MS, INTERNATIONAL PAINT LLC; AND MARGARET PARDY, MAG CONSULTING INC.

Several decades ago, tank linings used in the chemical, oil and gas, and water and wastewater industries were invariably based upon multi-coat, low-volume-solids, solvent-borne epoxies. At that time, the chemistries of these linings were relatively simple, based typically on Bis A or epoxy phenolic resins that were co-reacted with amine or amine adduct curing agents[1].

In the early days, for new tank applications, the life expectancy of these multi-coat linings in harsh chemical and thermal immersion environments was often just a few years. To improve matters, and particularly when lining pitted tank floors resulting from steel corrosion caused by acids or other corrosive media, or replacing existing poor-quality linings, either fiberglass or fiberglass chop strand was used to reinforce and upgrade linings to improve their service lives.

Today, however, more sophisticated and chemically-resistant linings based on advanced epoxy novolac chemistry have become the norm. Instead of using fiberglass reinforcement with a lining that will be applied to pitted steel, reinforcement of the linings can now be achieved by the incorporation of judiciously selected pigments. Many of these linings have little or no solvent content, can be applied in thick single-coat films direct to metal (DTM) and cure fast with return-to-service capabilities in less than a day. In addition, the linings can be engineered to comply with API652[2]. Hence, facility owners can extend the intervals between lining inspections.

Given the benefits accrued from using a self-priming, DTM solvent-free epoxy (SFE), why introduce a thin-film solvent-borne holding primer into the tank-lining scheme? Surely this could be a retrograde step and negatively impact productivity. Would not the use of such a holding primer be "penny-wise *but* pound-foolish"?

To reasonably answer these questions, either for new or old tank-lining work, it is instructive to address some key issues. These include (a) the nature of the holding primer and the breadth or narrowness of the definition of said holding primer, (b) the surface profile and pitting in the steel substrate prior to lining application, (c) the influence of solvent in a solvent-borne holding primer, (d) the productivity in terms of both time to complete the lining application and the condition of the applied lining as a function of holding primer use, and (e) the difference in performance of the lining system conferred by a solvent-borne, suitable holding primer.

THE NATURE OF SOLVENT-BORNE EPOXY HOLDING PRIMERS FOR TANK APPLICATIONS

From the outset, to assuage any concerns for lining performance in immersion service in tanks and vessels, the authors are not referring to the use of a weldable pre-construction primer commonly used in the shipbuilding industry where it may remain uncoated for up to a year. The type of holding primer referenced here is a high-performance tank lining often used as either the primer or finish in a high-performance thin-film multi-coat lining system in the oil and gas, or wastewater industries. If a weldable pre-construction primer had been used on the plates of a new tank, it must be completely removed by abrasive blasting to SSPC-SP 5/NACE No. 1, "White Metal Blast Cleaning" prior to application of the lining system.

Importantly, when it comes to the design of a solvent-borne epoxy holding primer for use beneath a thick-film SFE tank or vessel lining, there are several requirements that the holding primer should meet to ensure that the lining system can deliver the desired performance results.

Most thick-film SFE linings do not wet pitted steel properly due to their thixotropic nature and air trapped in pits cannot escape through the applied film. This can cause pinholing and discontinuities in the film. A properly designed holding primer, however, that contains solvents for lubricity and other flow and leveling agents will wet these irregular pitted surfaces and help trapped air to escape. As a result, an even surface for the SFE topcoat will eliminate any pinholes and other imperfections.

In a nutshell, the holding primer would ideally accomplish the following.

1. Meet the most stringent VOC regulations.
2. Dry fast and if possible, for some applications, have low-temperature-cure characteristics (32 F).
3. Have low viscosity and good wetting capabilities. At the same time, it should possess sufficient thixotropy so that it can be readily applied at 3-to-5 mils DFT.
4. Possess excellent chemical resistance equal to its specified SFE topcoat.
5. Have recoatability of at least two days at ambient temperatures and up to 30 days in some cases, with its SFE topcoat.
6. For safety reasons, possess a flash point above 80 F.

Several years ago, in the early days of using SFEs, many times an epoxy holding primer was used without paying attention to its chemical resistance. In stark contrast, nowadays, several lining manufacturers do offer more robust epoxy holding primers that

Getty Images / swisshippo

possess enhanced chemical resistance equal to the SFE topcoat.

SURFACE PROFILE AND PITTING IN THE STEEL TANK

Proper surface preparation and clean steel substrates with an appropriate surface profile are necessary for the application of high-build epoxy lining systems. For SFEs, recent work indicates that a deep profile of 2.5-to-3 mils is required for these linings to perform well in immersion service[1-4].

The authors also contend that in the case of high-build, single-coat and SFEs, the profile depth should be greater than 2.5-to-3 mils and preferably 3-to-4 mils in lining systems[7]. The profile should be jagged as opposed to having a peen pattern. Profile angularity, profile amplitude and profile peak-count density are all important factors when considering the corrosion resistance of immersion-grade linings.

Figure 1 shows a grit-blasted steel substrate with a 3-mil jagged profile that is well-suited for the application of a thin-film chemically resistant holding primer or a DTM-applied thick-film SFE for immersion service. In contrast, Figure 2 shows a 3-mil shot-blasted and smooth profile that is unsuitable for a comparable lining application.

Abrasive media are typically sharp and angular and can be made of steel grit or a variety of minerals. For tank-lining applications in the field, the authors are not in favor of recyclable grit for the surface preparation of steel surfaces. These recyclable steel abrasives can be used to remove existing linings and then the steel must be abrasive blasted with approved mineral abrasives.

With tanks, pitting corrosion can be very problematic to deal with in terms of properly applying a lining given the non-uniform geometries, shapes and sizes of pits above and below the steel substrate. For instance, pits can be semi-hemispherical, elongated and rounded, or undercutting beneath the steel. Then there are the issues of costs incurred and time taken to complete pit repair work.

When pits have arisen due to corrosion, they should be repaired either by grinding or welding, patching, or replacing the steel

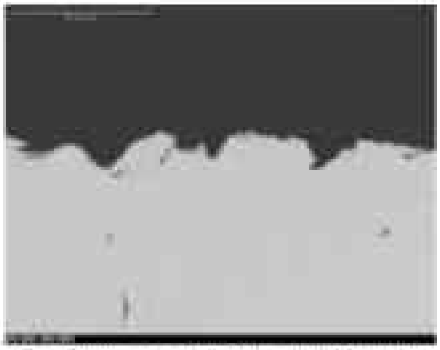


Fig. 1: Photomicrograph (200 times magnification) of abrasive-blasted steel with 3-mil angular pattern. Figures courtesy of the authors unless otherwise noted.

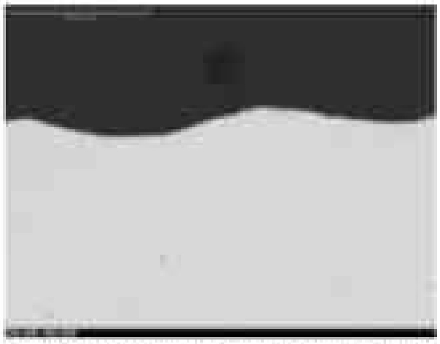


Fig. 2: Photomicrograph (200 times magnification) of abrasive- blasted steel with 3-mil peen pattern.

plates. Properly abrasive-blasted elliptical or wide shallow pits are often filled by squeegee-applied SFE.

While a full description of pitting is beyond the scope of this article, Figures 3, 4 and 5 (p. 24) show schematic diagrams and real-world examples of some of the types of pitting corrosion encountered in steel tank lining work.

Narrow, deep and vertical grain attack pitting can also pose problems in that full penetration and filling by the system primer and SFE topcoat is not assured[8].

Figure 6 (p. 26) shows how a solvent-borne epoxy holding primer has wet out a pit found in the crown of a pipe.

In cases where tank floors have been substantially corroded and pitted, certain owners are mandating that an SFE cannot be applied in a single-coat application even after filling the pits with an SFE caulk. Instead, those owners specify an application of a holding primer, then filling the pits, followed by an application of the SFE topcoat.

Project time permitting, other owners are electing to remove pitted steel plates and replace them with new ones and then apply the specified lining system.

THE INFLUENCE OF SOLVENT IN HOLDING PRIMERS

SFE DTM Linings With or Without Solvent-Borne Epoxy Holding Primers

In the context of tank and vessel epoxy lining systems, it is important to weigh the technical and performance merits of single-coat, SFE linings versus multi-coat solvent-borne epoxies or the use of a solvent-borne epoxy holding primer beneath a thick-film SFE.

Although by no means exhaustive, factors such as solvent effects, molecular weight, internal stresses, application characteristics, and inspection, repair and overall productivity are part of any comparative overview.

The absence of solvents in epoxy coatings can be beneficial for the following reasons[9]:

- The coating will meet or exceed VOC regulations and minimize fire risks, explosion hazards and solvent emissions.
- SFEs can be safer to use in confined spaces and are not to be thinned, as thinning would compromise the rate and degree of cure, depress the Tg, and lessen the coating's anticipated service life and the owner's performance expectations.
- A successful one-coat application is expected to save time and money.
- SFEs often possess better edge coverage on sharp edges and irregular surfaces.
- Their fast-set, quick-cure characteristics are ideal for fast-track tank and pipe projects as well as secondary containment applications.

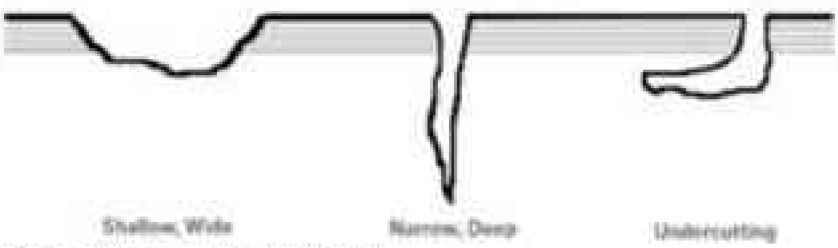


Fig. 3: Pictorial representation of pitting types.

Fig. 4: Pitting as evidenced in corroded steel tank bottoms.

Fig. 5: Cross section through pitted steel (10 times magnification) highlighting types and depths of pitting. Photos courtesy of Bill Johnson, Acuren Inc.

- There is no concern with solvent entrapment in these coatings as they are not thinned.

On the downside, SFE linings are often less chemically resistant. This is because higher-solids technology requires the use of lower-molecular-weight reactants which leads to the presence of more unreacted, monomer-like, less chemically resistant materials.

Typically, SFEs are viscous, have short pot lives, and despite being formulated with wetting agents such as modified silanes or siloxanes, exhibit inferior wetting properties compared to solvent-borne epoxies. Hence, the SFE may partially fill an abrasive-blasted surface, resulting in voids in the valleys of the profile which can prove damaging to in-service lining performance. Also, it is best to manufacture SFEs under a nitrogen blanket to minimize air entrained in the unmixed Part A and Part B components and minimize air voids (foam) in the single coat of the SFE film applied to steel. Once again, the latter can lead to deleterious lining performance.

It is noteworthy that in many retrofit projects, the intended application of one coat of SFE does not occur. If a second coat is necessary, uniform film builds and recoat times may be extremely difficult to achieve.

Importantly, a single-coat high-build SFE is unlikely to be conducive to application in poorly designed vessels with complex geometries.

Often overlooked are the appreciable residual internal stress buildups that can occur in SFE linings. An applicator is unlikely to have such stresses on his or her mind, but these stresses can result in coating failure as exemplified by detached SFEs on abrasive-blasted tank floors. Hence, somewhat poorer wet out/flow can prove deleterious in SFE systems. Why? Because solvents have lower surface tensions than resins and in solvent-free coatings, the beneficial wetting action of solvents is not present.

Another concern with viscous SFEs is any bridging of pits on retrofit applications where a thin, solvent-borne epoxy primer is more suitable. A truism is that small mistakes with one-coat systems have the potential for far bigger consequences than a mistake with multi-coat systems[illegible].

From some applicators' perspectives, viscous solvent-free epoxies are still considered to be specialty products that require sophisticated and expensive equipment to apply properly.

It cannot be overemphasized that there are many unseen advantages to using solvent-borne, multi-coat epoxy systems or a judiciously selected solvent-borne epoxy holding primer, and these advantages derive from the solvent itself. Solvents are often thought of as "the stuff that helps paint dry" in a uniform, controlled and beneficial manner. But they also have a crucial role in providing molecular mobility and lubricity. Solvents dissolve the higher-molecular-weight materials, facilitate the movement of building blocks in the development of a three-dimensional "molecular spaghetti" structure that evolves during the cure process, and help produce better film formation (much the same as spaghetti sauce helps otherwise sticky, starchy spaghetti move around).

Solvents in a holding primer therefore perform several useful functions.

- They tend to provide better wetting and improved adhesion in less internally stressed films.
- They dissolve higher-molecular-weight-polymerizing materials to produce more chemically resistant films.
- They facilitate a more controlled cure development.
- They afford the use of multi-coat epoxy linings that are applicator friendly and more conducive to achieving minimum and uniform film builds.

However, a concern with solvent-containing systems is the need to meet VOC regulations and the possibility of solvent entrapment (and osmotic blistering).

Fig. 6: Cross section through a pit demonstrating complete wetting of steel by multiple coats of a solvent-borne epoxy. Photo courtesy of Ray Abt.

Optical Microscopy: Deliberate Mechanical Damage of Linings With or Without Solvent-Borne Epoxy Holding Primers

In order to observe the difference that a solvent-borne epoxy holding primer/SFE makes compared to a direct-to-metal application of an SFE, two panels of each system were immersed for 10 minutes in liquid nitrogen. They were then subjected to reverse impact mechanical damage and where the coating disbonded, the profile in the steel was examined. Figure 7 shows that in the case of the epoxy holding primer, there was a significant amount of residual holding primer in the steel profile. In stark contrast, in the case of the panel with a single coat of SFE, there was almost no residual SFE in the profile.

Optical Microscopy: Cross Section of Linings With or Without Solvent-Borne Epoxy Holding Primers

A cross section of a solvent-borne epoxy holding primer topcoated with an SFE was compared and contrasted with the cross section of the same SFE applied directly to a steel surface. Close inspection of Figure 8 shows that in each case, the epoxy coating appears to have fully wetted out the steel profile. However, in the case of the DTM SFE, it is worth noting that the air voids (foam) are in close proximity to the steel profile, whereas

Fig. 7: Lining systems mechanically damaged after immersion in liquid nitrogen. Holding primer/SFE: residual holding primer (left) and SFE: no residual SFE lining (right).

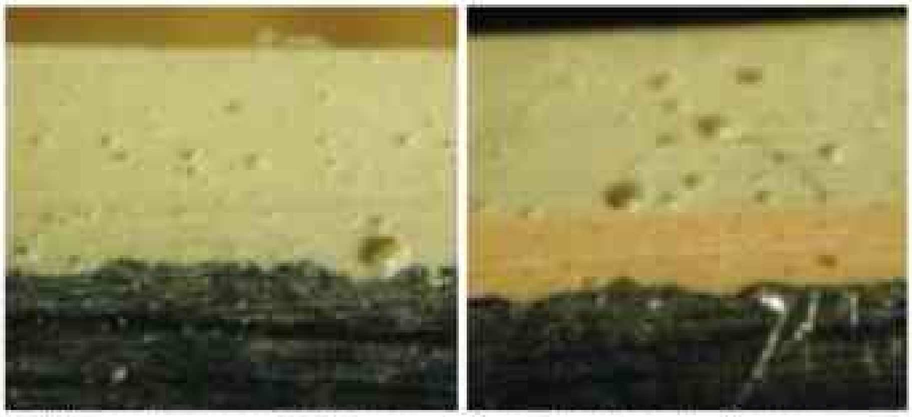


Fig. 8: Lining systems cross section. Holding primer/SFE: good wetting by the solvent-borne epoxy holding primer (left) and SFE: good wetting by the SFE (right).

the inclusion of a solvent-borne epoxy holding primer prevents foam from close contact with the underlying steel substrate. The uniform nature of the holding primer would clearly mitigate against a large number of pinholes being formed in the overall system.

PRODUCTIVITY: TIME TO COMPLETE A LINING APPLICATION AND LINING CONDITION

From the outset, the authors recommend that the specification authority in the pre-qualification and auditing process evaluate the third-party independent inspection company and preferred contractor, specific crew personnel and application equipment for the upcoming tank-lining project.

For predictability of success with the tank-lining project, a quality specification, quality application and quality inspection are all critically important.

To the chagrin of many facility owners, it is well-known that a tank with a pitted substrate will take longer to abrasive blast to a specified standard than will one with new steel. The time will depend on the condition of the substrate and the degree of pitting. If pitting is severe in such a tank, say, one of 100 feet in diameter, this may add one to two days to the schedule to abrasive blast and clean the lower one meter of the shell, the floor and all of the nozzles within the lower one meter of the shell.

For comparative purposes, let us consider the sequence and time line of applying SFE with and without a holding primer in a 100-foot-diameter tank where the environmental conditions are well controlled.

For the sake of brevity and simplicity, Day 1 is denoted as the day when abrasive blasting is completed.

Following are two hypothetical cases, both based on numerous real-life scenarios.

CASE 1: TANDEM SYSTEM — SOLVENT-BORNE EPOXY HOLDING PRIMER AND SFE TOPCOAT

Day 1

At this point, we assume acceptance of the abrasive blast, application of the stripe coat and spray application of the holding primer, and final acceptance of the abrasive-blast

Fig. 9: (L to R) Stripe coat with solvent-borne epoxy holding primer, full application of the holding primer and pits filled flush with epoxy caulk. Right-hand photo courtesy of Rick Jondreau, M.R. Consulting Inc.

cleanliness, soluble-salt levels being below the specified upper threshold level and surface profile.

Typically, the abrasive standard for linings will be SSPC-SP 5/NACE No. 1, white metal, or SSPC-SP 10/NACE No. 2, "Near-White Blast Cleaning," and the total soluble chloride levels would be less than $5 \mu g/cm^2$. The surface profile requirement for most thin solvent-borne epoxy holding primers applied at the specified 3-to-5 mils DFT is a sharp, jagged and thus angular shape of 2-to-4 mils and without a peen pattern.

Once the abrasive-blast cleanliness and surface profile is accepted, a thin-film stripe coat of the holding primer, thinned per the manufacturer's recommendation, is brush-applied to all welds, edges and other difficult-to-spray areas. The stripe coat is thinned to allow it to flow into undercuts and pits without overbuilding and causing solvent entrapment.

Once the stripe coat is applied, the applicators spray-apply the solvent-borne epoxy holding primer to all the steel surfaces to achieve the requisite 3-to-5 mils DFT. This range is important given that a heavier DFT of say, 7-to-9 mils may result in solvent entrapment, "pooling" into wider pits and corners of welds. While some contractors back-roll the holding primer, should solvent be trapped, it will eventually release much like a whale blowing water and the result is a small crater and weak spot in the lining system.

During spray application of the holding primer, the color of the material is important as it helps applicators visually if the color contrasts well with the SFE topcoat and abrasive-blasted steel. Mishaps during application of the holding primer can be readily repaired during inspection as the holding primer was applied in a thin coat.

Day 2: Inspection of Holding Primer and Filling of Pits (if required)

When the holding primer is dry, the applicators sand and remove debris and detail rough welds, sharp edges and pits with epoxy caulk prior to the topcoat application. The lower DFT holding primer will expose debris that may float onto the substrate during field application — debris visible for the workers to remove prior to application of the topcoat. A higher DFT of the holding primer may inadvertently bury debris if the latter is small in size.

Abrasive blast media is one form of debris commonly found embedded in the holding primer particularly along welds where it can be caught by air movement. Alternatively, the abrasive media may appear courtesy of windy conditions outside the tank or loosen and fall from floating roof seals and panels where it was trapped. Note that in tanks with no floating roof, dust and debris may fall onto the substrate from the upper areas particularly in the case of an older tank.

Applied by putty knife or trowel — depending upon the severity of the pitting — the specified epoxy caulk is worked into the pits and rendered flush with the surface. If the epoxy caulk is not applied this way it may float on top of the pits and may also cause excessive film build.

The epoxy-caulk-application step enhances the integrity of the lining and reduces holidays and other repairs at inspection time. In a new tank the SFE is often applied the day of inspection of the holding primer as epoxy-caulk work is minimal. By way of contrast, in an older and pitted tank — and depending on the degree of pitting and condition of the welds — it may take most of the shift to prepare the holding primer and apply epoxy caulk. It cannot be overstated that the recoat window of the epoxy caulk must be considered if the SFE is not slated for application until the following day.

Application of the SFE topcoat is now undertaken if no severe pitting is found. Figure 9 shows the appearance of a stripe coat and holding primer prior to topcoating with an SFE.

Day 3: SFE Inspection (possibly Day 4 if pitting is extensive)

During inspection of the SFE on both a new tank and pitted tank where a holding primer was applied, holidays are minimal. This is because sharp welds, undercutting and pits had been well-detailed prior to application. Furthermore, the DFT range is more consistent than if the SFE was applied direct to metal. Usually, with a good applicator, film-thickness repairs of the lining are minimal with just a few areas of lower DFT on wide-diameter tanks.

Table 1: Accelerated Laboratory Testing of Lining Systems: Holding Primer/SFE and SFE Direct-to-Metal.

Exposure Test	Test	Phase	Holding Primer/SFE	SFE
Autoclave TM 0185-2006 Duration: 14 days Temperature: 65 C (149 F) Pressure: 50 psi G 5% H_2S, 5% CO_2, 90% CH_4 H Sour Crude W 5% NaCl in Tap Water	Parallel Scribe Adhesion (A-E)	G H W	A A A	C B B
	ASTM D4541 Adhesion (psi)	G H W	3,762 4,055 3,113	3,933 5,676 5,186
	EIS @ 0.1 Hz ohm.cm²	G H W	9.8 x10^{11} 5.0 x10^{11} 5.0 x10^{11}	9.4 x10^{10} 6.4 x10^{10} 5.0 x10^{10}
Atlas Cell PAC TM0174 -2002 Duration: 28 days Temperature: 65 C (149 F) Pressure: 50 psi G 5% H_2S, 5% CO_2, 90% CH_4 H Sour Crude W 5% NaCl in Tap Water	Parallel Scribe Adhesion (A-E)	G H W	A A A	C C C
	ASTM D4541 Adhesion (A-E)	G H W	3,108 3,079 2,135	4,683 4,592 2,884
	EIS @ 0.1 Hz ohm.cm²	G H W	7.7 x10^{11} 8.8 x10^{11} 3.5 x10^{11}	8.0 x1010 7.4 x1010 3.5 x1010
Atlas Cell SAC TM0174 -2002 Temperature: 65 C (149 F) Thermal Gradient: 25C G Water H Sour Crude W 5% NaCl in Tap Water	Parallel Scribe Adhesion (A-E)	G H W	A A A	C C D
	ASTM D4541 Adhesion (psi)	G H W	3,552 3,599 3,388	2,966 4,101 830
	EIS @0.1 Hz ohm.cm²		ND	ND
Flexibility: CSA Z245.20-14 Section 12.11 (modified) Temperature: -30 C (-22 F)	Max Bend /PD		0.75 degrees	0.85 degrees
Hot Water Soak CSA Z245.20-14 (12.14) Duration: 28 days in Tap Water Temperature: 65 C (149 F)	Rating 1-5		Rating 1 (coating cannot be removed cleanly)	Rating 2 (<50% coating removed in small pieces)
Impact **CSA Z245.20-14 (12.12)** Temperature: -30 C (-22 F)	1.5 Joules 3.0 Joules		Pass Pass	Pass Pass
Taber Abrasion **ASTM D4060-14** 5,000 cycles	Wear cycles per mil > 600		4,570 average	4,372 average

All holding primer/SFE ASTM D4541 testing evidenced 100% cohesive failure in the primer.
All SFE ASTM D4541 testing evidenced a mix of cohesive, adhesive and glue failures.

A=No change/no disbondment, B=Slight change of adhesion (>50% still attached), C=Moderate loss of adhesion (<50% still attached), D=Severe loss of adhesion and E=Disbondment.

G, H, W = gas, hydrocarbon, water

On the subject 100-foot-diameter tank where a holding primer was applied by an efficient crew, inspection and repairs are completed in just one day.

Day 4: Follow-Up on Final Repairs and Curing Lining (possibly Day 5 if pitting is extensive)

When all of the repairs are dry, they are retested and may require further repair. For instance, the specified DFT may not have been achieved or the repair material may not have fully extended to cover holidays (along a long weld, for example). Hence, lining retest repairs are carried out if necessary, followed by final inspection.

All being well, the lining should appear to be brand new. It is then cured and the applicator demobilizes.

CASE 2: SFE APPLIED DIRECT-TO-METAL

Day 1

At this point, we assume acceptance of abrasive blast, application of stripe coat, and spray application of SFE and final acceptance of the abrasive-blast cleanliness, soluble-salt levels being below the specified upper threshold level and surface profile. To reiterate, the authors deem that the acceptable surface profile for an SFE applied direct-to-metal is a minimum of 3 mils and jagged in nature, as opposed to having a peen pattern.

Once the abrasive-blast standard specified for the project has been confirmed and the surface profile accepted; a thin-film stripe coat of a solvent-borne epoxy, thinned as recommended by the manufacturer, is applied to all welds, edges and other difficult-to-spray areas prior to application of the SFE. The thin-film stripe coat is thinned to allow it to flow into undercut and pits without overbuilding the stripe coat and causing solvent entrapment. The stripe coat must be dry before the direct-to-metal application of the SFE. Application of the SFE is then carried out if there is no pitting to be filled.

When applying an SFE DTM, the abrasive-blasted substrate may require filling due to the presence of pitting. Some contractors prefer to fill pits by squeegee during application of the SFE while others prefer to fill pits by hand trowel using an epoxy caulk. After completion of the abrasive blast, the steel substrate is rough. Hence, it may be more difficult and time-consuming for applicators to apply an SFE by squeegee or an epoxy caulk to pitted areas. The squeegee-applied SFE or epoxy-caulk application may well take longer than one shift to complete if the pitting is severe. If so, the recoat window of the caulk and edges of the squeegee-applied SFE must be considered with regard to the application of the SFE.

It is important that the color of the SFE contrasts with the substrate when applied direct to metal. A gray-colored SFE will not contrast well with the gray abrasive-blasted substrate. Unsurprisingly, a gray lining applied on a gray abrasive-blasted substrate can exacerbate difficulties ensuring proper lining coverage and film control. Mishaps during coating application cannot be cleaned up as well from an abrasive-blasted substrate given that the SFE is thicker and has a short pot life.

Day 2: Inspection (possibly Day 3 or 4 if pitting is severe)

During inspection of the SFE applied direct-to-metal, holidays and DFT repairs are more extensive. This is most likely to do with detailing the pitting and welds which cannot be completed as smoothly on an abrasive-blasted substrate compared to one with a thin-film holding primer.

Debris may also be the cause of more repairs, where abrasive smut may be buried and smaller remnants of fine-sized debris may not be visible to the naked eye. Abrasive-blast media is one form of debris commonly found embedded in the lining, particularly along welds where it is caught by air movement.

On a tank where an SFE was applied in a single-coat application — and particularly on a severely pitted substrate — holiday testing and repairs could be extensive and easily take two days to complete because the number of holidays is invariably far higher than if a holding primer was used. Making matters more difficult, the repairs are also more time-consuming due to the need to identify holidays and non-compliance with DFT requirements.

Day 3: Repairs (possibly Day 4 or 5 if pitting is severe)

It is possible for the schedule to be negatively impacted and go to Day 6 if it takes two days to conduct holiday testing and complete repairs.

Once dry, the repairs are retested and may require further repair. For instance, the specified DFT may not have been achieved or the repair material may not have fully extended to cover holidays (along a long weld, for example).

Day 4: Inspection and Repair (possibly Day 5 or 6 if pitting is severe)

It is also possible for the schedule to be negatively impacted and go to Day 7 if pitting was severe and repairs were extensive. If necessary, retesting the repairs can be carried out prior to final inspection and sign off.

It is important to note that as mentioned earlier, the overall visual result of an SFE applied over a holding primer is very good. However, in contrast, this may not be the case for an SFE applied direct-to-metal. In the latter case, more repair areas are often evidenced where up to 10 times more holidays are sometimes found and in need of repair. At best, the lining appearance is diminished. At worst the performance of the overall lining system will be more suspect.

In the final analysis, applying the SFE DTM may reduce the schedule by just one day, or it may equal the same number of days or take longer than the schedule using a holding primer followed by an SFE (particularly if pitting is severe and repairs are extensive).

PERFORMANCE OF THE LINING SYSTEM CONFERRED BY A HOLDING PRIMER

Having shown that there is little to choose from in terms of the schedule of applying a single-coat SFE DTM compared to the same lining applied over a carefully chosen solvent-borne epoxy holding primer, we must now examine what might result in performance from either of the two scenarios.

The linings evaluated in this work have been used for decades in oil-and-gas applications in tanks, pipes and vessels. Both the solvent-borne epoxy holding primer and solvent-free epoxy topcoat are epoxy novolacs.

Table 1 (p. 30) summarizes the results of a comparison between the accelerated laboratory testing of a direct-to-metal-applied SFE versus the same SFE applied over a chemically resistant epoxy holding primer.

The accelerated laboratory tests in Table 1 are those typically used in the oil patch to prescreen lining systems for oil patch use. Tests on each system were carried out at 65 C (149 F). The tests carried out by the authors were autoclave NACE TM0185-2006, "Standard Test Method - Evaluation of Internal Plastic Coatings for Corrosion Control of Tubular Goods by Autoclave Testing;" pressurized atlas cell NACE TM0174-2002, "Laboratory Methods for the Evaluation of Protective Coatings and Lining Materials on Metallic Substrates in Immersion Service" (modified); standard atlas cell NACE TM 0174-2002; hot water soak CSA Z245.20 SERIES-14, "Plant-applied external coatings for steel pipe," Section 12.14; flexibility CSA Z245.20 SERIES-14, Section 12.11 (modified); impact CSA Z245.20 SERIES-14, Section 12.12; and Taber abrasion ASTM D4060-14, "Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser."

These results indicate that the use of a compatible and high-performance holding primer for the SFE was advantageous. The tandem system approach resulted in improved wet adhesion of the two-coat system compared to the single coat of SFE. Not surprisingly, this can be seen in the superior parallel scribe and hot water soak results for the two-coat and chemically resistant solvent-borne epoxy holding primer topcoated with the SFE.

As noted in previous work by the authors, wet adhesion is a far more important indicator of performance than is dry adhesion in prescreening evaluations of candidate tank-lining systems. In contradistinction, better dry-adhesion results were obtained with the SFE applied directly to steel, but this result has little significance[2].

Not unexpectedly, the lining performance assessment using electrochemical impedance spectroscopy showed that there was very little difference in barrier properties between the two-coat and one-coat SFE lining systems. So, there was no loss of lining performance using an appropriate holding primer.

The application and performance perspectives of the two lining scenarios beg two crucial questions. First, is it more productive and cost-effective to apply an SFE direct-to-metal in a wide-diameter tank, for example, one with a diameter in excess of 60 feet? Second, does the SFE so applied in a single coat in a pitted tank engender the same level of confidence as the SFE applied over a judiciously selected holding primer? Based upon the authors' exploration in this article, the combined wisdom from years of working in the high-performance coatings industry and our considered opinions, the answer to both questions is "in most, but not all cases — no probably not."

And then there's the third and overarching question: is the use of a holding primer beneath a thick-film SFE in a tank-lining application — especially when the tank is pitted — likely to be "penny-wise or pound-foolish?" The answer is a resounding "penny-wise".

CONCLUSIONS

For pitted steel, it is often advantageous to use a judiciously chosen thin-film solvent-borne epoxy primer beneath a solvent-free epoxy lining rather than applying the SFE alone in a single-coat direct-to-metal application.

There is often considerably more remedial work after the application of a single-coat of SFE versus a holding primer topcoat with an SFE.

SFE linings are often applied in a single coat over non-pitted steel that has been properly prepared by abrasive blasting. For large-diameter tanks to hold the blast, it may be advantageous to use a holding primer.

It is often penny-wise and not pound-foolish to use an appropriate solvent-borne epoxy primer beneath an SFE in large-diameter tank applications.

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FEATURE

LONG-TERM CORROSION PROTECTION FOR BURIED PIPELINES:

CUTTING CATHODIC PROTECTION COST WITH NON-SHIELDING COATINGS

BY DR. JEFFREY DAVID ROGOZINSKI, SHERWIN-WILLIAMS PROTECTIVE & MARINE COATINGS

Buried transmission pipelines face a constant safety threat from corrosion. Left uncontrolled, corrosion is likely to deteriorate steel pipes and welds, creating weak spots that could lead to a catastrophic pipeline leak or rupture. As such, pipeline owners and operators must protect buried pipes to enhance safety. The type of protection they specify will determine its ability to mitigate corrosion over time, which influences a pipeline's level of safety, as well as its total cost of ownership.

Applying an impressed current cathodic protection (ICCP) system to long and large-diameter pipelines is normal to enhance their corrosion protection. ICCP systems help to minimize the electrochemical reactions that promote corrosion by applying an electric current to the pipe. In addition, pipeline owners and operators typically specify the application of an external barrier system to the pipe such as a coating or wrap. The barrier system provides the primary corrosion protection and must work synergistically with the ICCP system. A further and equally attractive aspect of the barrier coating is that it reduces the energy consumption requirements of the ICCP.

The combination of an applied barrier system and an energized ICCP system provides a highly effective method for slowing down corrosion. However, over long periods of time, all organic coatings are susceptible to the loss of barrier properties. As these properties diminish, the ICCP is still in place to mitigate potential corrosion events and the current demands on the ICCP are increased to compensate, which not only means greater energy expenses, but could also lead to coating adhesion reduction by a mechanism known as cathodic disbondment.

To improve their success in combatting corrosion over a long time, pipeline operators fortunately have some options. Ideally, they can implement a barrier system that is designed to resist cathodic disbondment and also enhance the backup ICCP system's corrosion-protection capabilities. Many such systems exist in the market today.

The best-performing barrier systems greatly reduce the flow of electrons to the pipe, but do not shield it entirely. This approach helps to minimize the ICCP system's long-term energy requirements — and therefore the overall cost of CP — while ensuring a sufficient electron flow to the pipe is still present for backup protection. A fusion-bonded epoxy (FBE) barrier system is one technology that is highly effective in this regard (Fig. 1). This article will review how the combination of FBEs and ICCP systems can help pipeline operators safely, efficiently and cost-effectively move assets.

Fig. 1: By combining an external fusion-bonded epoxy (FBE) barrier coating system (shown) with an impressed current cathodic protection (ICCP) system, pipeline operators can minimize corrosion on pipelines. Photos courtesy of the Sherwin-Williams Company.

FUNDAMENTALS OF CORROSION AND CP

Corrosion is an electrochemical process that involves the passage of an electric current (electrons) between two sites on a metal surface where different chemical reactions take place. These reactions are oxidation (which occurs at what are termed anodic sites) and reduction (at cathodic sites). There is a difference in potential between these two sites and this is the driving force behind corrosion. For steel, the reaction at the anode is depicted in Equation 1.

$$Fe \rightarrow Fe^{+} + + 2^{e-} \text{ (electrons)}$$

The steel's surface loses an electron and soluble iron ions are released, forming rust. As more electrons escape, oxidation accelerates, creating more rust. Eventually, that rust falls from the surface, leaving less of the original steel material remaining. For pipelines, any affected areas of the pipe substrate and/or welds will become thinner, creating an increased potential for stress cracking. Over time, the thinning steel could lead to a necessary reduction of the maximum allowable operating pressure (MAOP) within the pipeline to minimize stress on the steel. Even worse, the thinning steel could become too weak and lead to a catastrophic pipeline failure.

However, there must be a balance of charge, as energy is not lost or created. Therefore, electrons must pass through the steel from the anodic site to the cathodic site, where the reduction reaction depicted in Equation 2 takes place.

$$O_2 + 2H_2O + 4^{e-} \rightarrow 4\,OH^-$$

The overall reaction is depicted in Equation 3.

$$2Fe + O_2 - \rightarrow 2Fe(OH)_2$$

By convention, the flow of direct current in an electrical circuit is in the opposite direction to the flow of electrons, so at the anode, a low-voltage DC current flows off of the steel into, in this case, the surrounding soil. A CP system essentially reverses the current flows off of the steel surface, reversing the direction in Equation 1 and thus, prevents corrosion.

Fig. 2: Non-shielding FBE barrier coatings permit some electrical conductivity to the metal pipe so backup ICCP systems can maintain protection in areas of cathodic disbondment.

IMPRESSED CURRENT SYSTEMS (ICCP)

A typical ICCP system will feature an energized anode, or an array of anodes, buried in the ground. Made of metal, the anodes complete the circuit between the polarized pipe and the rectifier power source. The presence of water and oxygen (the electrolyte) underground allows the electrochemical reactions to take place by completing the electrical cell through the transfer of electrons from the sacrificial anodes to the cathode, or pipe. Because the flow of electrons is to the pipe instead of away from it, the anodes will corrode instead of the pipe. In other words, the lost electron from the anode will transfer to the pipe, as opposed to a lost electron from the pipe transferring to a molecule in the surrounding soil. The anodes therefore provide continued protection — at least until they corrode to the point of requiring replacement.

To apply CP to a buried pipeline, operators will energize the ICCP system and adjust the current to maintain CP. The size of the pipeline, the wall thickness of the pipe and the type and quality of any external barrier systems applied to the pipe will influence the current output needs. If the coating system degrades over time, that output need will increase because the coating will no longer be able to stop the flow of electrons. Monitoring for this phenomenon will help operators know when to intervene and increase the current output of the ICCP system. Doing so will help them maintain sufficient CP to decelerate corrosion and enable longer pipeline maintenance intervals.

REDUCING THE COST OF CP

The goal of an ICCP system is to maintain a positive charge on the pipe and sacrifice electrons from the anodes to protect the integrity of the pipe. However, even with sacrificial anodes properly installed, some electrons will flow from the pipe to the surrounding earth. When this happens, the pipe neutralizes and will need to be repolarized by applying a slightly greater charge to it. This is why barrier coatings are used, as they can help to reduce these voltage increases and therefore, reduce the cost of CP. These coatings minimize the flow of electrons from the pipe substrate and help it maintain a positive charge by creating a barrier that mitigates electron flow between the steel and the ground. The better this barrier system works on its own to prevent corrosion, the lower the cost of operating the backup ICCP system over time. However, the barrier shouldn't work too well, as we'll discuss.

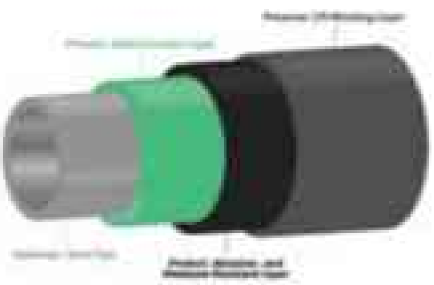

Fig. 3: FBE coatings may be applied in three layers to help minimize scrapes and deterioration that could expose the metal pipe substrate and promote corrosion. The three recommended layers include a base anticorrosion layer to prevent pipeline corrosion, an intermediate layer to protect the anticorrosion layer from wear and a UV-mitigation layer to preserve the first two layers before burying or submerging pipes.

Pipeline operators have two options for a protective barrier system. The first option — which may include solid film-backed polyethylene tapes, shrinkable polypropylene pipeline sleeves and cold-applied tapes — has the potential to provide barriers that are too good, thereby shielding the pipe completely. These shielding technologies all have high electrical resistivity, which prevents the free flow of electrons from anodes to the polarized pipe. According the Code of Federal Regulations, the United States does not permit the use of shielding technologies for pipeline CP. The alternative is to apply a non-shielding FBE coating that provides a barrier to electron flow, but not a full barrier, thereby allowing the ICCP system to remain effective (Fig. 2, p. 37).

Pipeline operators should therefore be wary of barrier systems that completely shield the pipe from electron flow because such systems greatly diminish the effectiveness of the complementary ICCP system. Not fully shielding the pipe sounds counterintuitive, but it makes sense when one considers that electrons from the ICCP system must be able to flow to the pipe to complete the flow of directly applied energy and mitigate the unwanted flow of electrons away from the pipe, which would cause oxidation. If the barrier coating effectively blocks the electron flow, then it cannot optimally work with the ICCP and its use should be reconsidered.

The guidance for the use of non-shielding coating technologies comes from the Pipeline and Hazardous Materials Safety Administration (PHMSA), a division of the U.S. Department of Transportation. The organization sets policies for the safe transportation of energy and other hazardous materials via transmission pipelines and states: "Pipeline segments must have a modern non-shielding to cathodic protection external coating on the pipe and girth welds." PHMSA considers FBE coatings to be modern non-shielding pipe coatings.

The reason PHMSA does not permit complete shielding of the pipe is because a full barrier will compromise the overall effectiveness of the ICCP system. A non-shielding FBE barrier will provide corrosion protection by reducing the potential flow of electrons to the pipe; however, the barrier will allow some electrical charge to flow through the coating to the steel pipe substrate. This flow is necessary for the ICCP system to maintain its backup protection against corrosion.

The backup protection of an ICCP system is of particular importance if the pipeline coating has a defect or holiday that represents a weak point that is susceptible to increased cathodic disbondment of the coating. The use of a non-shielding FBE coating will allow the current to flow through the coating such that electrons can still find those defect areas and help protect the pipe from oxidation. If the pipeline featured a shielding technology instead, the electrons wouldn't be able to penetrate the barrier to

Fig. 4: A preventive anticorrosion FBE layer applied to pipes should offer good adhesion and resistance to cracking, cold flow and softening over a broad temperature range.

Fig. 5: An abrasion-resistant coating will help protect pipes from scratches and scrapes as they're dragged across soil and gravel during installation and operation.

reach the pipe surface below. In this case, the electrical current will be limited — or fully blocked — from reaching the holiday area. Therefore, the effectiveness of the backup ICCP system will be minimized, potentially to the point of rendering it useless.

Realizing Long-Term CP Savings

By allowing the electrical current from an ICCP system to reach the steel pipe substrate, non-shielding FBE barrier coating systems actually enhance the ICCP system's ability to serve as a backup corrosion-mitigation system. The coatings also help to reduce the long-term energy costs of the backup system by mitigating corrosion themselves. To optimize this energy savings, it is helpful to specify an FBE coating system that features minimal cathodic disbondment potential. In addition, pipeline owners and operators may want to consider applying two additional protective coating layers to the pipe, building them up one layer at a time to reinforce the corrosion-prevention capability of the base FBE coating (Fig. 3, p. 37).

To enhance corrosion resistance, the base layer should be an anticorrosion FBE coating that offers consistent porosity resistance during application. This resistance will help to minimize voids in the coating, which could otherwise cause premature coating failure and eventual cathodic disbondment. In addition, the anticorrosion FBE should offer excellent adhesion to steel and outstanding resistance to cracking, cold flow and softening over a broad temperature range (Fig. 4, p. 39). These features will ensure the coating can resist cathodic disbondment — and therefore help to prevent corrosion — in a wide range of environments.

The next two layers are optional but recommended. First, an abrasion-resistant FBE coating is recommended to protect the base anticorrosion layer (Fig. 5, p. 39). Such coatings offer protection from damage during handling and installation that could cut through the base layer, exposing unprotected metal pipe. The final optional layer is a topcoat designed to preserve the two lower layers against ultraviolet (UV) degradation. This layer is especially advantageous if the coated pipe will be exposed aboveground for an extended period during storage or the inevitable installation delays.

Pipeline owners and operators should specify the appropriate level of corrosion protection to help them achieve long-term success, while also helping to reduce the cost of maintaining CP. An anticorrosion barrier system that is able to adhere to pipes and welds over the long term and is resistant to cathodic disbondment will require less energy to maintain CP. Adding an abrasion-resistant coating and a UV-stable topcoat to the base layer will improve outcomes. With a suitable non-shielding barrier system in place, current from the ICCP system will flow to the pipe and provide complementary CP benefits. Following these guidelines will help pipeline owners and operators enhance the long-term corrosion protection of their assets, while also reducing the cost of that protection.

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INSPECTING CUI SYSTEMS WITH EQUIPMENT IN SERVICE

Getty Images / zorazhuang

BY PETER BOCK, PERFORMANCE POLYMERS AMERICAS LLC

Corrosion under insulation (CUI) can be a plant maintenance manager's worst nightmare, and finding CUI can be like trying to read a book without opening the cover. The story is there; you know it's there, but you can't see it. Most industrial plants and many commercial facilities have insulated piping, vessels and process equipment; all of these are subject to CUI attack to different degrees, but petroleum refineries, chemical processing and similar heavy industrial facilities are particularly vulnerable because of their large-scale operations, extreme temperatures and potentially corrosive environments.

Insulation is used to reduce required energy input (whether for hot or cold processes), to ease movement of process materials and intermediates, to maintain process stability, to prevent degradation of fractioned or partially processed components and of the finished product, to provide personal protection for employees working in the process area and even to provide environmental protection. While we generally think of CUI and industrial process insulation in terms of elevated temperatures like those found in an oil refinery, there are many facilities that require insulation for cold service, for cyclic ambient/hot/ambient service or even for cold/hot/cold service.

As examples of hot and cold service requiring insulated equipment in the same facility — for heavy industries, think of a natural gas shipping terminal that may alternately cool incoming gas to liquefy it for shipment or heat incoming liquefied natural gas (LNG) to re-gasify it for outgoing pipeline entry. As a lighter example, a dairy processing plant will receive refrigerated milk, heat-pasteurize it, and then blend it into ice cream before freezing, packing and shipping out the finished product. It all requires insulation and whether the insulated piping and vessels are carbon steel, stainless or duplex; all of the surfaces under insulation are subject to CUI.

A proper insulation system consists of a thin metal or plastic outer covering jacket, the required thickness of insulation and a paint or metallic CUI-resistant coating to keep the steel underneath from rusting. In theory, the jacketing has no leaky seams or cracks to let in water, the insulation — which is mostly air — does not absorb any water and the CUI coating is totally resistant to any water that might work its way through the insulation. Of course, in real life things might be quite different.

In reality, sheet metal jacketing is fitted up from hundreds or thousands of sections. Some of those will leak at their joints from day one; others will suffer mechanical damage during years of service and be crushed or poked into letting water in. Nonmetallic jacketing may crack, rip or be perforated during its service life. Insulation is supposed to be hydrophobic

— water resistant. One of the best types of insulation sold today brags in its marketing that during a 60-day test it only absorbs about 90 percent of its weight in water. Except for foam glass, all insulation absorbs available water. CUI systems are normally expected to last a decade or longer. So, the thin layer of CUI coating or metallizing between the insulation and the substrate is the final barrier that is supposed to keep that steel substrate from rusting.

At the substrate, the environment is the same temperature as the process material inside the pipe or vessel — hot, cold or cyclic. The exposure is intermittent immersion in a mild chemical — water that got through the leaky jacketing plus whatever chemicals that water had picked up from the plant environment above the jacketing, and then whatever may have leached out of the insulation. If the vessel or pipe carries hot product, the CUI coating is also exposed to a steam interface every time the substrate exceeds 100 C (212 F). For cold product, cyclic freeze/thaw is equally severe. Overall, the CUI environment is one of the most aggressive corrosion environments in industrial service.

Fig. 1: Older storage tank with OSHA 1910.119 wall-thickness inspection ports placed for easy access along the stairs. This is not where major corrosion is expected to occur. All figures courtesy of the author unless otherwise noted.

Visual observation is the most common and easiest method of inspecting coatings; for CUI, it is impossible. Once an insulated unit is placed in service, the CUI coating should be inspected on a regular basis and repaired or replaced as needed. But because it is hidden under jacketing and insulation and can't be seen, the jacketing and insulation must be removed and then replaced after the inspection and any needed surface preparation and coating have been performed.

Traditional insulation and jacketing are not reusable. Besides the possible cost of scaffolding required for access, there is the cost of removing and properly disposing of old insulation and jacketing and then the replacement cost for new insulation and jacketing, plus loss of production if the unit is taken out of service. To reduce these staggering costs and avoid the possibility of failure from unseen corrosion, most owners of insulated equipment follow risk-based inspection (RBI) programs, as outlined in API Recommended Practice 580, "Risk-based Inspection" and API Recommended Practice 581, "Risk-based Inspection Technology." Insulated equipment is evaluated for risk of corrosion and impact of failure, and very small areas with the highest risk of corrosion and failure impact are inspected at scheduled intervals.

This same concept has been in effect for decades for inspecting piping and vessels for internal corrosion. OSHA 1910.119, "Process safety management of highly hazardous chemicals," requires regular nondestructive testing of "mechanical equipment capable of catastrophic release of toxic, reactive, flammable or explosive chemicals." Insulated piping and vessels subject to OSHA 1910.119 have openable inspection ports in the jacketing at specified intervals. The inspector opens the outer cover, removes the wad of probably wet insulation filling the hole in the main insulation, exposing the coated substrate beneath, takes a contact reading of the pipe- or vessel-wall thickness and replaces the insulation plug and port cover.

In the bad old days, wall-thickness inspection was done with bulky, cumbersome portable X-ray equipment. Today it is done with compact portable electronics that can be programmed to report spot wall-thickness readings to a laptop or tablet, eliminating much of the inspector's paperwork burden, but in most cases, access and contact are still required. Because of the required access, inspection ports tend to be placed to provide easy reach and only along existing walks, stairways or balconies (Fig. 1). Unfortunately, CUI is never limited to these areas and relying on data from inspection ports does not produce a complete or satisfactory CUI inspection program.

Wall-thickness readings can only indicate total thickness loss. It requires far more sophisticated testing or removal of jacketing and insulation to determine whether the loss is interior corrosion/erosion or external CUI. Physical access is still required, as is removal and proper replacement of each inspection port cover by the inspecting technician to prevent future water entry under the jacketing.

THERMAL IMAGING

The development of the thermal imaging cameras has allowed the CUI inspector to take a step back from direct contact. These cameras can be used from a distance and without removing jacketing and insulation. They give false-color images of the piping, vessel or equipment and insulation, indicating temperature variations as different colors and shades.

Thermal imaging results can be compared with historical RBI survey data to find unexpected hot (or cold) spots and variance from expected operating temperatures or temperature gradients. They do not give a direct indication of CUI but can be used to identify trouble spots and to bypass inspection of areas not showing a problem. Thermal imaging is also useful when repeated over time, to detect deterioration or changing states of insulation, jacketing and CUI coating by comparing past and current images of the same area.

In a typical thermal camera image for CUI inspection, light colors indicate hot surfaces with darker colors indicating cooler temperatures. On an insulated, jacketed, hot product pipe with no drain holes in the jacketing, occasional strips of black thermal image on the bottom of the insulated pipe simply mean that water has gotten in and is pooling there, a normal and expected CUI situation. Areas where the entire pipe circumference is light-colored indicate no water inside the insulation and probably little or no CUI. An area where half the circumference is black, or a dark shade, shows a high probability of excess water and a high likelihood of CUI. This is the time and place to spend money building scaffolding and removing insulation and jacketing to confirm a potential problem. Thermal imaging is a huge step forward in reducing required access and direct visual inspection by highlighting the most likely CUI trouble spots. Combined with a thorough RBI program, thermal imaging can provide cost-effective inspection results as well as peace of mind.

NON-CONTACT WALL-THICKNESS SENSORS

Another step back from CUI inspection requiring direct contact with the substrate is a recently developed system using permanently installed, battery-free, radio-frequency-identification- (RFID-) tagged, wireless ultrasonic sensors for non-contact wall-thickness measurement (NCWTS). This system combines a microelectronic wall-thickness sensor permanently attached to the substrate (under or in the middle of the CUI coating system) with an antenna similar to those used in highway toll tag systems. The whole NCWTS sender unit is smaller than the diameter of a hockey puck and has the thickness of a fifty-cent coin.

The NCWTS sender is activated by a hand-held reader instrument the size and weight of a small ball-peen hammer. The reader does not need to touch the sender but has to be near it and aimed at it. The non-contact reader inductively activates the sensor, which takes a wall-thickness reading and reports to the reader. The keyword here is "non-contact" (Fig. 2).

There are still limitations in the basic concept, but they can be engineered out. Each NCWTS reads only at the site to which it has been attached, but sending units can be placed as frequently as an owner desires. Thick layers of wet insulation and metal jacketing cannot be penetrated by the reader; the simple answer here is a nonmetallic access port cover permanently sealed to the metal jacketing. A cavity can be left in the insulation, immediately beneath the nonmetallic cover, or a flat plastic antenna extension gadget can run from the substrate to the underside of the sealed nonmetallic access port cover. If an owner desires, as many as 15 NCWTS senders can have antenna extensions, each up to several feet long, feeding to the same nonmetallic access port. Because each sender has a unique RFID tag, a single reader can access multiple senders at a single access port and store the wall-thickness readings or immediately send them to inspection software that electronically files the reported readings in the appropriate location on a chart or diagram of the unit being inspected.

Unlike vampires in the movies, our CUI inspector can't turn into a bat and fly up to inspect a critical elbow or joint that has no ladder or walkway access. But wait ... yes, he can. Sort of. The original design of the NCWTS reader unit had an accessory attachment at the end of the reader that could be hooked to a long (or adjustable-length) fiberglass pole, allowing the reader head to be brought close enough to a sender while the inspector controlled the reader from the other end of the pole. Over the past year, that has become outdated, though still useful technology.

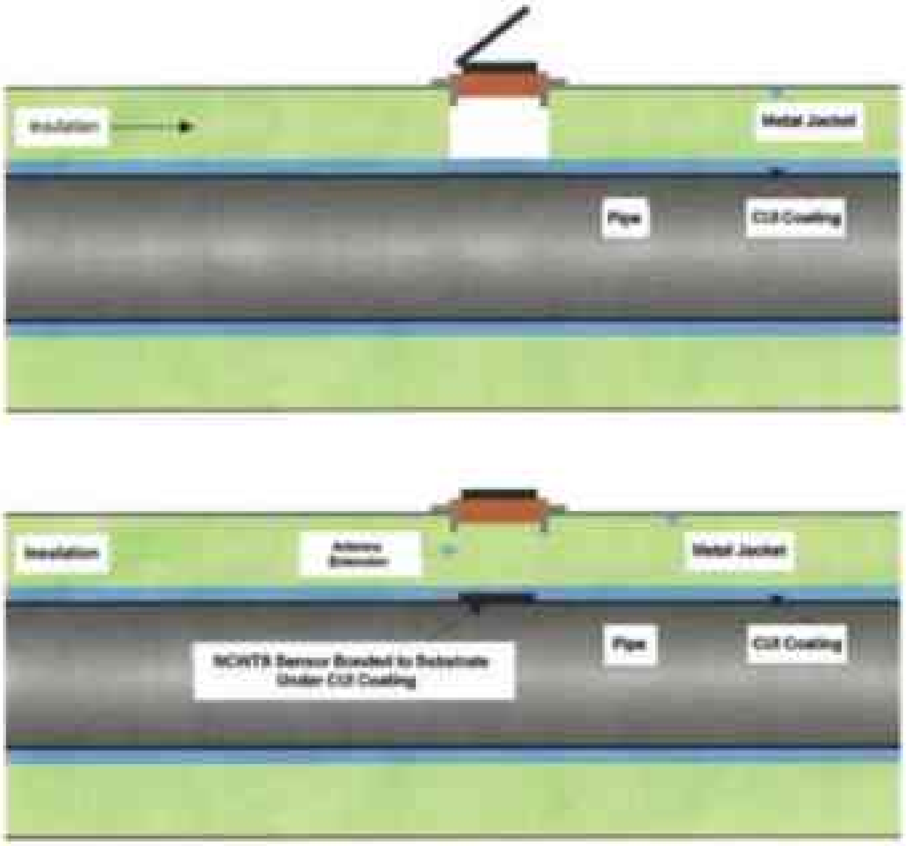


Fig. 2: Traditional inspection port with opening cover for inspection (top) and permanently sealed inspection port with NCWTS sensor (bottom).

Drones

Today, a special remote-control reader unit can be attached to a drone and — local plant safety regulations permitting — the drone can approach sealed access ports and take non-contact wall-thickness readings from the NCWTS senders beneath them. Wall-thickness readings can now be taken at regular intervals from locations with no climbing access, which would have previously required building scaffolding or rope access from a crane. Wall-thickness readings can also be taken from pipe and vessel undersides, backsides, and any place where a drone can be safely maneuvered in and out. Multiple senders can allow far more frequent wall-thickness check locations and readings than were reachable or affordable in the past (Fig. 3).

The NCWTS system is initially expensive and requires better planning than is normally done for the placement of OSHA 1910.119 inspection ports, but it eliminates the need for contact when reading, for direct access and for potentially leaky open/close access ports. The resultant readings are still only of total wall thickness. Without visual inspection, NCWTS cannot tell whether wall loss is internal, external, or both, although in real life, failure of the


Fig. 3: An overhead rack stuffed with pipes, many of them insulated, is ideal for a thermal-imaging-camera survey, which can be done from ground level and will quickly show which pipes have problems with insulation, jacketing and possibly CUI.

NCWTS sender usually indicates that CUI has disbonded the sender from the substrate. RBI and removal of jacketing and insulation will still be required, but less frequently than if working without NCWTS. The combination of RBI, thermal imaging and NCWTS allows far more thorough CUI inspection at far lower expenditure of time and money.

Two non-electronic concepts that are also making CUI inspectors and plant maintenance managers happier than they used to be, are jacketing with drain holes installed at the appropriate locations and removable tie-on insulation blankets.

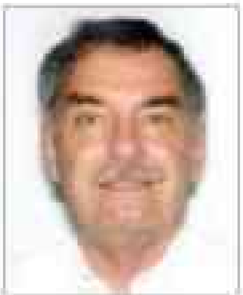
API Recommended Practice 583, "Corrosion Under Insulation and Fireproofing," and its NACE counterpart, SP0198-2017-SG, "Control of Corrosion Under Thermal Insulation and Fireproofing Materials — A Systems Approach," both strongly imply that leakage of water into insulation under metal jacketing is all but inevitable. For decades, the best practice was to attempt to make the metal jacketing as waterproof as possible, but sometimes this resulted in the lower half of metal jacketing forming a bathtub with no drain.

A few canny engineers cut strategically located drain openings in the jacketing on the bottoms of vessels and large diameter pipe, with the simple idea that yes, the water is inevitably going to get in, and we are simply providing a place where it can get out. That concept is now gaining acceptance to the degree that pre-perforated metal jacketing and preformed insulation and jacketing with drain holes on the bottom are now available. Just remember: holes only go on the bottom and must be placed so that water from rain, runoff and occasional deluges cannot be absorbed through the drain openings.

Flexible fabric jacketed insulation blankets have been used for decades on moderate-temperature equipment that required frequent insulation removal for inspection and repair, or that vibrated. Typically, fiberglass blanket was encased in a silicone-aluminized fabric, usually of woven glass fiber. Both the insulation value of the blanket and the temperature tolerance of the fabric on the substrate side were limited. Today, the better insulation value of thin aerogel insulation blankets and availability of higher-temperature-tolerant jacketing fabric have expanded the concept of reusable blankets far beyond the mufflers and exhaust piping on which they were used in the past (Fig. 4).


Fig. 4: Removable, reusable insulation blankets with flexible jacketing on both sides allow removal, replacement and inspection of the entire area under the blanket.

ABOUT THE AUTHOR



Peter Bock, owner and president of Performance Polymers Americas, is a petrochemical coatings, insulation and CUI specialist based in Houston. He is a U.S. Air Force veteran and holds degrees from Tulane University and the University of Northern Colorado. Bock has 42 years of corrosion-control experience worldwide and teaches annual courses on CUI. Bock is a NACE-certified Coating Inspector (Level III), is active in industry organizations, has been widely published and has presented numerous papers. He is past chairman of the NACE Central Area Board of Trustees, is a *JPCL* contributing editor, a *JPCL* Readers' Choice Award recipient and the recipient of two *JPCL* Editor's Awards. **JPCL**

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NMI Industrial Holdings
Norfolk Coating Services, LLC
NOR-LAG Coatings Ltd.
Northwest Sandblast & Paint LLC
Norton Sandblasting Equipment
Novatek Corporation
Nu Way Industrial Waste
Management LLC
NUCO Painting Corporation
Nusteel Fabricators, Inc.
Nut Communication &
Marketing Strategies
Nyhus Enterprises, LLC
O.T. Neighoff & Sons, Inc.
Odle, Inc.
Offshore Painting Services Ltd.
Oil Patch Sandblast & Paint Ltd.
Old Colony Construction, LLC
Olimag Sand, Inc.
Olympus And Associates, Inc.
Olympus Painting Contractors, Inc.
Olympus Painting, LLC
Omega Coatings & Construction, LLC
Ontario Painting
Contractors Association
Optimiza Protective & Consulting, SL
P & L Metalcrafts LLC
P & W Painting Contractors Inc.
P S Bruckel Inc.
P&P Contracting, Inc.
Pacific High Technology
Engineering Services
Pacific Painting Co. Inc.
PAE
Paige Decking
Paige Floor Covering Specialists
Paint and Coatings Manufacturers
Nigeria PLC
Paint Platoon USA &
Coatings Inspectors
Paint Supply Company
Painters & Allied Trades – LMCI
Painters USA, Inc.
Panther Industrial Painting, LLC
Park Derochie Coatings
(Saskatchewan) Inc.
Park Derochie, Inc.
Partner Industrial, LP
Paul N. Gardner Company, Inc.
PCI International, Inc.
Peabody & Associates, Inc.
Pelco Structural, LLC
Penington Painting Company
Performance Blasting & Coating
Performance Industrial
Phoenix Australasia
Phoenix Fabricators & Erectors LLC
Piasecki Steel Construction Corp.
Pinnacle Central Company
Planet Inc.
Polyset
Pop's Painting, Inc.
Poseidon Construction
Precision Welding & Fabrication
Preferred, Inc. -Fort Wayne
Prezioso Nigeria (Insulation Painting &
Engineering Services Ltd.)
Prime Coatings, Inc.
Prime Time Coatings, Inc.
Principle Industrial Services, LLC
Prospectrum Coatings Bvba
Pt Berger Batam
Public Utilities Maintenance, Inc.
Puget Sound Coatings Inc.
Purcell P & C, LLC
Pyeroy
PYR Preservation Services, Inc. dba PYR
Q.E.D. Systems, Inc.
Qualicoat Inc.
Quality Linings & Painting, Inc.
Quantum Technical Services
Quincy Industrial Painting Co.
Quinn Consulting Services, Inc.
R & B Protective Coatings, Inc.
R & S Steel, LLC
R. J. Forbes Painting Contractor Inc.
R.B. Hilton Limited
Rader Coating Technology (Shanghai)
Co., Ltd.
Rainbow, Inc.
Randell Industrial Services Ltd.
Rapid-Prep, LLC
Raven Lining Systems
Ravi Engineering & Land Surveying, PC
Rawhide Construction Service
RBG Trinidad and Tobago Limited
RBW Enterprises
Recal Recubrimientos, SA De CV
Redi-Strip Metal Cleaning Canada Ltd.
Regal Industrial Corporation
Reglas Painting Company, Inc.
Reichle Incorporated
Reliable Coatings LLC
Remington & Vernick Engineers
Revolution Industrial Coatings
Rhino Linings Corporation
Rhinoceros Ltd.
Riley Industrial Services, Inc.
Ring Power Corporation
Rizzo Brothers Painting Contractors Inc.
Robroy Industries
Rogers Industries, LLC
Ross Rex Industrial Painters Ltd.
Rotha Contracting Company, Inc.
Rover Contracting Inc.
Royal Bridge Inc.
Rpn Recubrimientos Polymericos Del
Noroeste Sa De Cv
S & D Industrial Painting Inc.
S & S Bridge Painting, Inc.
S & S Coatings, Inc.
S. David & Company LLC
Sabelhaus West, Inc.
SAFE Systems, Inc.
Safespan Platform Systems, Inc.
Saffo Contractors, Inc.
Safway Services LLC
Sahara Sandblasting and Painting Ltd.
Samac Painting
San-Blast-Ture
Sand Express
SARL EPI-CA
Sasyma Coatings SL
Saxon Enterprises
SBAS Training Services
Scicon Worldwide BVBA
SDB Engineers & Constructors Inc.
Seaway Painting LLC
Secondary Services, Inc.
See Hup Seng Cp Pte. Ltd.
Seifert Construction Inc.
Seminole Equipment, Inc.
SES Infrastructure Services LLC
Shanghai Genesis Chemmical Industry
Co. Ltd.
Shanghai Sunowchem Technology Co
Shanghai Zenhua Heavy Industries
Co. Ltd.
Shenhua United Construction Co. Ltd.
Shenzhen Asianway Corrosion
Protection Engineering Co., Ltd.
Sherwin-Williams Industrial & Marine
Coating China

Shimmick Construction
SII Industrial Minerals, Inc.
Silverline Finishing, Inc.
Simpson Sandblasting And Special
Coatings, Inc.
Sky Climber Access Solutions
Skyline Painting, Inc.
Skyline Steel LLC
SME Steel Contractors
Soil & Materials Engineers, Inc.
Solent Protective Coatings Ltd.
Somay Q Technologies (CBC America)
Southeast Bridge FL Corp.
Southern Paint & Waterproofing Co.
Southern Painting & Blasting, LLC
Southern Road & Bridge, LLC
Southland Painting Corporation
Spartan Contracting, LLC
Special Equipment Safety Supervision
Inspection Institute of Jiangsu Province
Specialist Painting Group
Specialty Application Services, Inc.
Specialty Finishes, LLC
Specialty Groups, Inc.
Specialty Polymer Coatings, Inc.
Specialty Products, Inc.
Spectrum Painting Ltd.
Spider
Spiegel Industrial
Sponge-Jet, Inc.
SRT Sales And Service, LLC
Stantec
Steel Fabricators of Monroe, LLC
Steel Management Systems, LLC
Steel Service
Sto Corp
Stork Technical Services
Structural Coatings, Inc.
Subsea Coating Technologies LLC
Sullivan-Palatek, Inc.
Sulzer Mixpac USA, Inc.
Superior Industrial Maintenance Co.
Superior Painting Company, Inc.
SuperVac Truck & More, Inc.
Surface Prep Supply
Surface Preparation & Coatings, LLC
Swanson & Youngdale, Inc.
Symmetric Painting, LLC
T & W Industrial Services LLC
T. Bailey, Inc.
T. Tex Equipment L.P.
Tank Services Inc.
Tarps Manufacturing, Inc.
Tavlor Devices, Inc.
Taylor's Industrial Coatings, Inc.
TDJ Group, Inc.
Team Industries, Inc.
TECHNIJA II
Techno Coatings, Inc.
Technofink
Tecnico Corporation
Temp-Coat Brand Products, LLC
Termobarranquilla S.A. E.S.P.
Tesla Nanocoatings, Inc.
Testex, Inc.
Texan Stone LLC
Thomarios
Thomas Industrial Coatings, Inc.
Thompson Pipe Group – Pressure
TIB Chemicals AG
Tidal Corrosion Services LLC
Tidewater Staffing, Inc.
Tioga Air Heaters, LLC
Titan Industrial Services
Titan Tool
TJC Painting Contractors, Inc.
TMI Coatings, Inc.
Tower Inspection Inc.
Tower Maintenance Corp.
Tower Power Group Painting Co. Ltd.
TQC Sheen
The Tradesmen Group, Inc.
Travis Industries, LLC
TRB Industrial Coatings Inc.
TRC Engineers, Inc.
Trelawny SPT Ltd.
Triple H Construction, Inc.
Tri-State Painting, LLC
True Inspection Services
TRUQC LLC
Turman Commercial Painters
Turner Coatings LLC
Turner Industries Group, LLC
Twilight S.A. De C.V.
U.S. Tank Painting, Inc.
UHP Projects, Inc.
Uniteam Training
University of Akron / NCERCAMP
US Coatings, Inc.
US Minerals
Utility Service Company, Inc.
Valentus Specialty Chemicals
Valor Defense Solutions, Inc.
Van Air Systems
Vastas Vaif Armatur Sanayi Ticaret A.S.
Vector Technologies Ltd.
Veritas Steel LLC
Ville Platte Iron Works, Inc.
Virna Construction Corp.
Virnas Painting Co., Inc.
Vision Painting & Decorating Services
Vision Point Systems
Vulcan Painters, Inc.
W G Beaumont & Son Ltd.
W O Watters Company
W S Bunch Company
W W Enroughty & Son, Inc.
W&W-AFCO Steel, LLC
The Warehouse Rentals and Supplies
Wartsila Defense, Inc.
Wasser High-Tech Coatings, Inc.
Waterblasting Technologies
Watson Coatings Inc.
Weir Valves and Controls UK Ltd.
Wenrich Painting, Inc.
Western Industrial Services, Ltd.
Wheelblast, Inc.
Winoa USA
WIWA LLC
Wm. B. Saleh Co.
Worldwide Industries, Inc.
Worth Contracting, Inc.
Woyt Industries, LLC
Yankee Fiber Control, Inc.
Yellow Creek Coating Services
YYK Enterprises, Inc.
Zack Painting Company, Inc.
Zebron Corporation
Zibo Taa Metal Technology Co. Ltd.
Ziegler Industries Inc.
Zingametall BVBA
Zirtec Industria & Comercio LTDA
ZRC Worldwide

Sustaining Members

Abhe & Svoboda, Inc.
Actemium - OEngenharia LTDA
Allen Blasting & Coating, Inc.
Alpine Painting &
Sandblasting Contractors
American Institute of Steel
Construction (AISC)
Apache Industrial Services
Arcosa Industries de Mexico
Arkansas Painting & Specialties, Inc.
ASCO - American Stripping Company
Atsalis Brothers Painting Co.
Avalotis Corporation
Brand Industrial Services
Brock Services, LLC
C.A. Hull
Cannon Sline Industrial
Carboline Canada
CCI Inspection Services, Inc.
Certified Coatings Company
Champion Painting Specialty
Services Corp.
CL Coatings Division of BrandSafway
Clemco Industries Corp.
Composite Technology &
Infrastructure LLC
Consolidated Pipe And Supply, Inc.
Cor-Ray Painting Co.
Corrosion Resistance
Covestro LLC
Dalco By Brand Safway
DBM Services, Inc.
Delta Sandblasting Co. Inc.
Deltak Environmental Coating
Services, Inc.
Demilec USA
Des-O-Tex Division Crossfield
Products Corp.
Dow Chemical Company
Dunn-Edwards Corporation
Eagle Industrial Painting LLC
Eagle Industries
Endura Manufacturing Company Ltd.
Ergonarmor
Evonik Corporation (ECA)
F.D. Thomas, Inc.
FCA International
Fletch's Sandblasting & Painting, Inc.
G.C. Zarnas & Company, Inc.
General Dynamics NASSCO - Norfolk
GNP Ceramics LLC
Harsco Metals & Minerals
Hempel USA, Inc.
High Steel Structures, Inc.
International Marine and Industrial
Applicators LLC
Jotun Paints, Inc.
Landmark Structures
Line-X Corp.
Long Painting Company
Los Angeles Painting and Finishing
Contractors Association (LAPFCA)
MACSEAL Service LTDA
Main Industries Inc.
Mandros Painting, Inc.
Manufacturas Metalicas AJAX S.A.
DE C.V.
Marco
Marine Hydraulics International Inc.
MC Painting
Mid-Atlantic Coatings, Inc.
Mistras Group Inc.
MOBLEYSAFWAY Solutions, LLC
Mohawk Northeast, Inc.
National Bridge LLC
Naval Coating, Inc.
Niles Industrial Coatings LLC
North Star Painting Co., Inc.
Northwest Sandblasting & Painting, Inc.
Olympic Enterprises Inc.
Olympos Painting Inc.
Ostrom Painting & Sandblasting, Inc.
PCI - Performance Contracting Inc.
Phillips Industrial Services Corp.
Polygon
Pro Blast Technology Inc.
Pro Tank - Professional Tank Cleaning
& Sandblasting
Profile Finishing Systems, Inc.
Propaint (1625820 Alberta Ltd.)
Quality Coatings of Virginia, Inc.
Quiñones Painting Inc.
Redwood Painting Company, Inc.
Rust-Oleum Corporation
San Diego Powder & Protective
Coatings, Inc.
Scott Derr Painting Co., LLC
Shopworks Inc.
South Bay Sand Blasting &
Tank Cleaning
Sprayroq Inc.
Stebbins Engineering &
Manufacturing Co.
Surface Technologies Corporation
T. F. Warren Group
Tank Industry Consultants, Inc.
Termarust Technologies
Thermal Spray Solutions Inc.
TruAbrasives by Strategic Materials
TSC Training Academy
Unified Field Services Corporation
Vanwin Coatings of VA, LLC
Williams Specialty Services, LLC

32 F

The temperature at which a holding primer should ideally be able to cure, with a flash point above 80 F for safety reasons.

See page 22.

49 CFR 192.112

The United States Code of Federal Regulations that prohibits the use of shielding technologies for cathodic protection of pipelines.

See page 38.

OSHA 1910.119

"Process safety management of highly hazardous chemicals," which requires regular nondestructive testing of mechanical equipment capable of catastrophic release of toxic, reactive, flammable or explosive chemicals.

See page 42.

1989

The year that late *JPCL* contributor Mark Schilling authored, "Caveat Emptor: Understanding Coating Failures in Petrochemical Plants," which emphasized the importance of coating fundamentals in avoiding failures — concepts that are still crucial today.

See page 14.

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Painters whose skills were compared by measuring film-thickness distribution during roller application of a three-coat system on wastewater clarifiers.

See page 18.

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JPCL articles that were selected by readers as 2018 winners of the *JPCL* Readers' Choice Awards, presented Feb. 11 at the SSPC Coatings+ awards luncheon in Orlando.

See page 4.