AWWA D102-11:
Providing the Water Industry with Better Standards to Protect Welded Steel Tanks

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In October of 2011, the latest revision of AWWA's D102 standard for coating welded steel water storage tanks went into effect after a lengthy consensus-based industry evaluation of coating technologies. The standard establishes minimum requirements for steel surface preparation and generic classifications of Outside Coating Systems (OCS) and Inside Coating Systems (ICS).

Most notable among the items that changed was the revision to Inside Coating System No. 3 (ICS-3). The ultra high solids, medium film coatings now recognized by ICS-3 have advanced design features meant to significantly mitigate early corrosion failures. The attributes of these coatings include edge retentive properties, higher solids and lower solvent content, high flash point, medium film thickness of 20-50 mils, 24-hour curing cycles and NSF/ANSI 61 approvals. The D102 revision demonstrates acceptance by the water storage industry to advance its technique of preventing corrosion in welded steel water storage tanks in the most sustainable manner possible.

Until the latest revision, the most recent iteration of the D102 standard (D102-06) encompassed only thin film epoxy lining systems, generally two or three coat systems that utilize moisture cure, zinc rich primers or epoxy primers followed by epoxy intermediate and topcoats. The minimum total thickness of thin film systems is 8 to 12 mils. Now ICS-3 provides for the use of epoxy coatings with 96% or better volume solids to protect the interior surfaces of steel water storage tanks where the minimum film thickness is 20 mils Dry Film Thickness (DFT).

This paper will present an overview of the ultra high solids, medium film systems newly recognized by AWWA, and demonstrate the ways in which adhering to the standard can deliver a sustainable method for achieving environmentally sound and measurable service life improvements. Reviewing and comparing the history of internal linings for water storage tanks and the development of medium film coatings over the past 20 years in the adjacent marine and petrochemical industries will provide background and discussion points. The paper is intended to provide a source for performance evaluation methods and resources, installation and specification considerations, and associated long-term investment studies comparing traditional thin and medium film linings for the water storage industry.

The D102 Standard and the Evolution of Coating Systems for Water Storage

Welded steel water storage tanks have been in use for more than 100 years; the oldest registered and functioning tank, located in Whitewater, Wisconsin, was built in 1889. The American Water Works Association Board of Directors approved the first edition of the D102 Standard on February 11, 1964. Earlier editions co-authored by a joint committee of AWWA and the

New England Water Works Association (NEWWA) date back to May 24, 1954. The standard represented a consensus of the water supply industry in regard to the products or systems that would provide satisfactory service to the industry at large.

The standard review and revision process is undertaken by the D102 Revision Task Force, a committee made up of general interest, producer and user members of the AWWA. It convenes on a regular basis and evaluates the latest in technologies to protect steel water tanks from corrosion.

Coatings have always been considered an essential part of the corrosion control process to protect steel surfaces. Over many years, corrosion in steel water storage tanks, ship tanks and petrochemical tanks has been studied and corrosion control measures developed for interior, under side, and exterior surfaces of those tanks. When early corrosion occurs on surfaces that have been coated, inadequate installation, insufficient DFT, poor film thickness on sharp edges or irregular surfaces, pinholes, voids, holidays, or incompatibility with cathodic protection are considered the main causes.

Before conventional thin film epoxy became the lining product of choice for tank interior surfaces, municipalities originally turned to coal tar enamel, which was known for its ease of use, flexibility, thick films and relatively simple application. As toxicology review and evaluation procedures improved, and to comply with more stringent health codes, multiple coat thin film epoxy systems became the standard lining system for steel water tank interiors.

In 2008, a white paper, 308729 – "Expected Service Life and Cost Considerations for Maintenance and New Construction Protective Coating Work," was presented at the NACE Corrosion Conference & Expo by members of KTA Tator Inc. As the most comprehensive discussion of tank lining service life to that point, the paper was designed to assist the coatings engineer or specifier in identifying candidate protective coating systems for specific industrial environments. It provided some guidelines for developing term life cycle costs, economic analysis and justification, and net present value analysis for installed lining systems.

The paper also provided a total service life estimate of 12-15 years for thin film coating systems in potable water immersion. The estimate included the practical service life plus a calculated number of years where touch up would be performed to extend the total service life. At the end of the total service life, full removal and recoating would occur.

The Experience of Adjacent Industries in Evolving Coating Technology for Tank Linings

For many years, the U.S. Navy was plagued with early corrosion and coating failures while trying to maintain chemical holding tanks, water storage tanks, ballast and fuel tanks, and other critical ship structures in immersion service. These structures are full of hard edges, weld seams, irregular surfaces, and hard to access surfaces much like the roof and rafter systems seen every day in steel water storage tanks.

In 1995, the Navy began a five-year program to improve its materials and practices for preserving tanks with coatings. At that time, the Navy's traditional solvent-borne thin film tank coating systems had a life expectancy of two to ten years. The goal of the program was to extend the service life of coating systems beyond 20 years.

The steps identified as key to achieving that goal were: "Identify a coating system that will perform in a severe operating environment and adequately protect sharp edges and weld defects. Ensure adequate equipment and process controls, including enhanced surface preparation requirement and strict quality control of surface preparation and coating application. Control the coating process and ensure an adequate return on investment." (Thomas & Webb, 2006)

Thomas & Webb's recommendation stemmed from a simple finding: "This wide range in performance was due to the variability of application quality. A thorough review of Navy tank coating failures revealed failure modes consistent with edge failure – especially in sharp-edged stiffeners, failure initiation at weld defects and weld spatter, premature failures at previously repaired areas, insufficient paint thickness, inadequate surface preparation and residual contamination leading to blistering and delamination, and inappropriate environmental conditions during surface preparation and coating application." (Thomas & Webb, 2006)

The Navy identified several solvent-free epoxy coatings to address this issue, including edge-retentive formulations designed to be applied at 20-40 mils DFT. These products were intended to prevent early failures at edges and irregular surfaces where traditional epoxy shrinks during the curing phase and was providing inadequate performance. A medium film thickness of 20-40 mils was identified as the best-performing DFT. The ultra high solids, edge-retentive formulations generally improved the thickness and performance of the anti-corrosive barrier on these irregular surfaces.

Seeing the promise in these medium film coating systems, the Navy adopted the Performance Specification Coating Systems for Ship Structures, MIL PRF 23236, directly addressing the importance of edge retention performance by specifying that "the retained percent average coating retention on a 90 degree outside edge of no less than three specimens shall be an average minimum of 70% of the measured dry film thickness on the flat areas of the test specimen." (Navy, 2009) Some manufacturers began to develop solvent-free coatings to meet this standard, and complying coatings were issued a Qualified Products List number (QPL).

Solvent-free medium film coating systems advanced the performance of internal linings for the U.S. Navy. In a 2006 U.S. Navy Submarine Preservation conference, new studies were presented where the use of MIL 23236 approved coatings were shown to have increased the practical service life in a chemical holding tank from two years to ten years and in a ballast tank from three years to 20.

The MIL 23236 case histories from coating corrosive, salt-laden ballast tanks and the NACE industry survey provide historical data and industry discussion that directly supports the improved service life expectations of edge retentive, medium film coatings for immersion service in potable water storage tanks. Now, the estimated practical service life of ultra high solids, medium film coatings (ICS-3) in potable water storage is 20 years.

Confirming Performance Through Testing

Evaluation of ultra high solids, medium film coatings for future projects should also include relevant laboratory performance tests to help evaluate physical properties such as the coating's abrasion resistance and film hardness, adhesion to the substrate, elongation and flexural characteristics, moisture resistance, and performance when working in conjunction with cathodic protection. ASTM has a number of tests (Table 1) that specifiers and owners can use to develop specifications.

Table 1

Characteristic	ASTM Standard Number and Title	
Abrasion Resistance	ASTM D4060	Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
Pencil Hardness	ASTM D3363	Standard Test Method for Film Hardness by Pencil Test
Adhesion	ASTM D4541	Standard Test Method for Pull Off Strength of Coatings using Portable Adhesion Testers
Shore D Hardness	ASTM D2240	Standard Test Method for Rubber Property – Durometer Hardness
Elongation	ASTM D638	Standard Test Method for Tensile Properties of Plastics
Flexibility	ASTM D522	Standard Test Method for Mandrel Bend Test of Attached Organic Coatings
Flexural Strength / Modulus	ASTM D790	Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
Moisture Condensation Resistance	ASTM D4585	Practice for Testing Water Resistance of Coatings using Controlled Condensation
Cathodic Disbondment	ASTM G8	Standard Test Methods for Cathodic Disbonding of Pipeline Coatings

Referring to ASTM standards, MIL – PRF 23236 Performance Specification Type VII, Class 9, Grade C for potable water storage, and the AWWA C210 Performance Standard, a list of acceptable performance criteria is available to develop a potable water storage tank lining specification using common coating system options.

Table 2

Common Coating System Options: AWWA D102-11: (ICS-3) Inside Coating System Number 3		
Option 1:	Option 2:	Option 3:
Prime: MCU Zinc Primer, 2-4 mils DFT	Prime: Epoxy Primer, 2-8 mils DFT	N/A
Finish: 96% VS Epoxy, 20-35 mils DFT	Finish: 96% VS Epoxy, 20-35 mils DFT	Finish: 96% VS Epoxy, 20-50 mils DFT

ICS-3 includes an optional primer with a minimum of 1 mil DFT, which is typically used for shop priming new fabricated steel. A single coat of epoxy finish is applied to the primed surface or directly to properly cleaned steel at a minimum of 20 mils DFT. Per the AWWA standard, “the optional primer can be a two component epoxy primer, inorganic zinc rich primer, or an organic zinc rich primer. If an inorganic zinc-rich primer is specified, it shall be in accordance with SSPC-Paint 20 type 1-B or 1-C. If an organic zinc rich primer is specified, it shall be in accordance with SSPC-Paint 20, type II, chemically cured. The two-component epoxy topcoat shall have a minimum volume solids content of 96 percent and shall comply with the performance requirements outlined in ANSI/AWWA C210.” (AWWA, 2011)

As shown above, these coating systems provide higher total DFT compared to the ICS-1, ICS-2 and ICS-5 thin film epoxy lining systems. Due to the minimum amount of solvent, these ultra high solids, medium film coatings can be applied as thicker protection barriers and still maintain ANSI/NSF 61 approvals.

Installation and Specification Considerations

When identifying the interior tank space, it is common to picture it divided into two parts – interior normally wet and interior normally dry. Interior wet spaces are subjected to constant immersion and typically are the wall and floor areas of the water tank from the overflow down. Interior wet areas include the interior ceiling or roof, support rafters, girders and crow’s nest, which are located above the top capacity level (TCL) also known as the vapor zone.

The vapor zone is a harsh environment and is an area of concern, especially for maintaining the structural integrity of these valuable assets. Coating systems must perform without the support of cathodic protection. As in the case of the ballast tank in the Navy studies, the roof and rafter space contains many hard to reach areas, hard edges not properly ground, and multiple angles to paint. This vapor space continues to cycle from wet to dry and hot to cold, and is minimally ventilated. Due to the difficulty of accessing and coating these areas, two coat systems are typically selected. Options 1 and 2 in Table 2 are multicoat systems that use proven organic zinc rich primers or epoxy primers with edge retentive characteristics. The ultra high solids, medium film finish coat formulations meeting MIL 23236 QPL approval will improve the thickness and performance of the anti-corrosive barrier coating while using the same number of application steps.

From the overflow down, walls and columns can be accessed with travelling scissor lifts or scaffolding. The floors are also more accessible. Applicators can take advantage of these open spaces to apply a single coat of epoxy at 20-50 mils DFT and achieve a holiday-free surface. Coating option 3 (Table 2) with a single finish coat applied directly to prepared steel surfaces provides improved process efficiencies for applying, holiday inspecting and curing of potable water storage tank linings for interior wet spaces.

As an application process, one coat of ultra high solids, medium film epoxy on steel as an immersion grade lining has become common practice in the petrochemical industry. During the storage of crude oil in a floating roof tank, residual produced water separates from the crude and eventually settles in the bottom three feet of the storage tank. In many cases, only the floor and shell are lined in the petrochemical storage tanks, as the water component is considered the most corrosive medium. These tanks have also been painted with two-coat phenolic epoxy systems, but as contractors, equipment and coatings have evolved, single coat medium film epoxy systems have become normal practice in this industry.

Application equipment for ultra high solids, medium film coatings has also advanced. ICS-3 epoxy coatings are typically applied by brush or spray. Stripe coats are applied by brush over weld seams, edges, or irregular surfaces and can be immediately coated “wet over wet” with spray-applied material.

Ultra high solids epoxy coating with greater than 96% volume solids cure rapidly but also have an extremely short pot life. Due to the limited amount of time available for application after the coating system components are mixed, this type of coating (depending on the manufacturer’s formulation) is best applied with “mix-on-demand” heated plural component equipment. Contractors working in the water storage industry are becoming increasingly familiar with these systems, often having been trained by SSPC with courses on airless spray application C12, abrasive blasting C7, and plural component basics to elevate their knowledge-based skills. SSPC provides these and QP level certifications to contractors and also provides a means to qualify contractors’ performance abilities and track records. In addition, the XP70 mechanical proportioner unit was introduced in 2009 and provides a simpler set up to deliver 100% solids coatings to a steel surface.

Calculating Financial Impact

Financially evaluating the feasibility of a coating system and comparing one system versus another requires certain assumptions about initial costs and total service life of the installed system. Initial fees associated with the installation of a coating system include the cost of paint on a project, surface preparation, application, inspection, ventilation/dehumidification, repairs, curing and disinfection. After installation, factors associated with the coating system’s longevity after it is installed should also be considered in looking at long-term performance of a coating system.

Returning to the NACE 2008 study method, we can use this model to calculate a given coating system’s total service life. The total life of a coating system in the NACE 2008 model starts with the practical service life expectancy combined with routine maintenance painting sequences.

- The practical life, “P,” is considered to be the time up until 5 to 10% coating breakdown occurs (SSPC-Vis Grad 4), and active rusting of the substrate is present.
- Typical maintenance painting sequence includes touch up painting that occurs at Practical or “P” service life as defined.
- Maintenance repaint occurs at P Life + 33% (P x 1.33).
- Full repaint occurs at Year of Maintenance Repaint = 50% of Practical “P” Life (P x 1.50).

As noted in the “Expected Service Life and Cost Considerations for Maintenance and New Construction Protective Coating Work” paper, the economic analysis and justification process “is sometimes misunderstood and overly complicated for paint and coating systems. Capital items require intricate analyses to identify the full financial impact. Paint and coating systems are basically expense items without salvage value or depreciation considerations. However, they are tax deductible in most instances. Only a few calculations are needed to compare one system with another to measure each system’s true cost in comparable dollars.” (Helsel, Lanterman, & Wissmar, 2008)

“For each system used, list the timing number and cost of painting operations required to protect the structure for its projected life. This should include such items as original painting, touch-up, maintenance repaint, and full repaints. The cost of each painting operation should be calculated in three categories:

- At Current Cost Levels.
- At Future Value Levels: the current cost with inflation included. How much will it cost, in inflated dollars in the year scheduled.
- At Present Value Levels: the present worth of the inflated cost (NFV) in monies today invested at current interest rates.

By making these calculations for each of the system's painting operations, the true cost and number of painting operations can be compared, and the coating selection made on a comparable basis." (Helsel, Lanterman, & Wissmar, 2008)

Table 3

ICS-3: Medium Film Epoxy: 17 year practical service life								
Painting operation	**Original Painting**	**Touch - Up Year 17**	**Full Repaint Year 25**	**Touch - Up Year 42**	**Full Repaint Year 51**	**Touch - Up Year 68**	**Full Repaint Year 76**	**Total**
Year of Operation	0	17	25.5	42.5	51	68	76.5	93.5
Cost in Current $	$6.50	$2.60	$8.78	$2.60	$8.78	$2.60	$8.78	$40.63
FV Cost Future value @ 3% inflation	-$6.50	-$4.30	-$18.65	-$9.13	-$39.62	-$19.40	-$84.20	-$181.80
PV costs Present value @ 6% interest	$6.50	$1.60	$4.22	$0.77	$2.03	$0.37	$0.98	$16.46

ICS-2: Thin Film Epoxy: 13 year practical service life								
Painting operation	**Original Painting**	**Touch - Up Year 13**	**Full Repaint Year 19**	**Touch - Up Year 32**	**Full Repaint Year 39**	**Touch - Up Year 52**	**Full Repaint Year 58**	**Total**
Year of Operation	0	13	19.5	32.5	39	52	58.5	71.5
Cost in Current $	$6.00	$2.40	$8.10	$2.40	$8.10	$2.40	$8.10	$37.50
FV Cost Future value @ 3% inflation	-$6.00	-$3.52	-$14.41	-$6.27	-$25.65	-$11.16	-$45.65	-$112.68
PV costs Present value @ 6% interest	$6.00	$1.65	$4.63	$0.94	$2.64	$0.54	$1.51	$17.92

ICS-1: Thin Film Epoxy: 8 year practical service life								
Painting operation	**Original Painting**	**Touch - Up Year 8**	**Full Repaint Year 12**	**Touch - Up Year 20**	**Full Repaint Year 24**	**Touch - Up Year 32**	**Full Repaint Year 36**	**Total**
Year of Operation	0	8	12	20	24	32	36	44
Cost in Current $	$6.00	$2.40	$8.10	$2.40	$8.10	$2.40	$8.10	$37.50
FV Cost Future value @ 3% inflation	-$6.00	-$3.04	-$11.55	-$4.33	-$16.47	-$6.18	-$23.48	-$71.05
PV costs Present value @ 6% interest	$6.00	$1.91	$5.74	$1.35	$4.07	$0.96	$2.88	$22.90

Table 3 provides a simple model for investigating the economics of using ultra high solids, medium film coating systems compared to the thin film epoxy systems. In order to calculate values, the following constants were assumed.

- Installation Value $6 per square foot. Installation costs for both multiple coat, thin film epoxy systems and the ultra high solids, medium film systems remain the same and include previously noted initial fee items.

- Cost of Materials Value $0.55 per square foot. Material costs for plural component systems are more expensive because more material is applied during application. Calculating a standard ICS-2 three coat epoxy system at 12 mils DFT with 20% of materials lost to overspray is $0.50 per square foot. Calculating a standard ICS-3 single coat epoxy system at 30 mils DFT with 20% of materials lost to overspray is $1.05 per square foot. The additional material costs of the ultra high solids, medium film system will be added to the total installation cost of the ICS-3.

- ICS-1 Thin Film Coating Value: 8 year practical service life. The practical service life for a two-coat system is listed as 5 years in ballast tanks per the U.S. Navy and listed as 8 years in the NACE presentation. Minimum film thickness is 8 mils in two coats.

- ICS-2 Thin Film Coating Value: 13 year practical service life. The practical service life for a three-coat system is listed as 5 years in ballast tanks per the U.S. Navy and listed as 15 years in the NACE presentation. Striking a balance between the two produces this practice service life value. Minimum thickness is 12 mils in three coats.

- ICS-3 Medium Film Coating Value: 17 year practical service life. The practical service life of solvent-less medium film coatings is listed as 20 years in ballast tanks per the Navy and 15 years in the NACE study. Striking a balance between the two produces this practical service life value. Minimum film thickness is 20 mils in one or two coats.

- Touch up Value: Original Cost x 40%. Only one touch up will be completed after the coating has reached the end of its practical service life. The cost associated with this work is calculated as the Original Cost x 40%.

- Replacement Value: Original Cost x 135%. The expected total service life of the coating in this model is complete after one maintenance touch up occurs at the end of the practical service life. The time value is calculated at the practical service life plus (P x 0.5). All coatings are replaced using appropriate surface preparation and installation procedures. The cost associated with this work is calculated as the Original Cost x 135%.

- Inflation Value: 3% per year. Inflation for the past ten years has fluctuated between 2.5 and 3%.

- Investment Value: 6% per year. Investment opportunities are not yielding 8% constantly.

Three full cycles were chosen using the above calculation points so that the results could provide insight into the maintenance cycle and total service life of each system as well as the cost values for a period above 50 years. In this evaluation, three coating cycles using ICS-3 produced 93.5 years of operation at a 2012 Present Value Cost of $16.46 per square foot. Three cycles of ICS-2 provided 71.5 years of operation at a 2012 Present Value Cost of $17.92 per square foot. Finally, three cycles of ICS-1 provided only 44 years of operation at a 2012 Present Value Cost of $22.90 per square foot.

In Conclusion

Best application practices and a well defined QC and QA procedure together remain essential for the successful installation and long-term performance of both thin film and medium film coating systems. (Kaznoff & Brinckerhoff, 2005) Many design features of the medium film coating system, directly impacting safety and environmental compliance, can be advantageous to contractors and inspectors and will also provide potential benefits for asset owners to consider. (JPCL Staff, 2009)

The chemical formulation of the ultra high solids, medium film coating systems translates to low VOC content because of their low or no solvent composition. Low solvent content in the coating system provides a better method to pass extraction tests, mitigate taste and odor issues, and ensure water quality for customer distribution.

Low VOC content, ultra high solids, medium film coating systems now provide a longer proven track record of performance when compared to reformulated thin film epoxy and a safer means to comply with continued rule changes from air quality management districts. As is the case with the South Coast Air Quality Management District (SCAQMD) in 2006 and the Ozone Transport Commission (OTC) in 2009, VOC restrictions for industrial maintenance coatings – in this case, pertaining to tank linings for water storage – are being pushed lower and lower. (South Coast Air Quality Management District, 2007)

Improved application efficiencies are gained when using the ultra high solids, medium film coatings that will effectively lower installation costs. The design features of these systems include single coat applications capable of 24 hour cure-to-service. Single coat applications reduce the extra time and cost involved in applying multiple coat thin film systems which normally require 5-12 days of controlled ventilated curing before a tank is disinfected and subsequently filled. Further time and cost benefits can be found when extended cure-to-service cycles of 5-12 days with thin film epoxy systems are reduced to 24 hours. Also reduced are the time and costs associated with rental and power fees for dehumidification and heating units. Shorter curing cycles reduce stagnant job activity and return the asset to an income-generating condition more quickly.

Municipalities, just as is the U.S. Navy, are under continuing financial pressure and have limited resources. (Business Week Staff, 2011) Preservation of expensive assets is essential to minimize early structural repair or replacement costs. AWWA D102-11 ICS-3 encourages the water industry to follow in the footsteps of the marine and petrochemical industry and provides a standard to develop sustainable practices that better preserve and extend the service life of steel water storage tanks, for a lowest total cost of ownership.

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