Present Levels of Corrosion Protection on Ferrous Water Piping in Municipal Infrastructure: A Manufacturer's Perspective

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In 2000, the Water Infrastructure Network estimated that costs of corrosion for drinking water systems were $19.95 billion per year in the U.S. Although most agencies address corrosion on the inside of pipes with linings, corrosion on the outside of pipes often is addressed with a less-than-scientific approach. This article discusses the approach taken by the steel and ductile iron pipe industry to address the corrosion issue by assigning a risk value to the level of protection taken.

According to the American Water Works Association (AWWA) (Denver, Colorado) industry database, there are ~876,000 miles (1,483,000 km) of municipal water piping in the U.S. In a study conducted by CC Technologies Laboratories, Inc. (Dublin, Ohio) with support from the U.S. Department of Transportation's Federal Highway Administration (Washington, D.C.) and NACE International,[1] the total estimated cost of corrosion in the U.S. is $276 billion per year. Of that total cost, $19.25 billion is attributed to drinking water systems and $13.25 billion is assigned to sewer systems. Contributing to the total estimate were the cost of replacing aging infrastructure; the cost of unaccounted-for water through leaks; the cost of corrosion inhibitors; and the cost of linings, coatings, and cathodic protection (CP). It may seem surprising that drinking water and sewage infrastructure corrosion costs are higher than those of any other sector that was studied. What has caused the sector to lag, and what can be done to improve the situation?

Findings of the Cost of Corrosion Study

The study states the following about corrosion:

- External corrosion can be effectively mitigated by the application of coatings and CP.
- Although the systems have problems of their own, the initial cost for installing coatings and CP on new systems is almost always warranted because large maintenance cost savings can be achieved over the life of the piping system.
- External corrosion can be prevented…with the use of external coatings and the application of CP.

The Cost of Corrosion Study also examined some of the major reasons why the problem is so extensive. Some of the conclusions include:

- A major barrier to progress in corrosion management is the absence of complete and up-to-date information on all water systems. Limited communication among water utilities restricts the spread of information about—and thus the awareness and implementation of—available corrosion control technologies, such as new coatings and CP.
- A second barrier to progress in corrosion management is the lack of understanding and awareness of corrosion problems at the local level. Also, the limited amount of time dedicated to solving corrosion problems contributes to this obstacle.
- Educating maintenance personnel and water system designers about corrosion would allow corrosion engineering to play a more effective role in this sector.

Addressing Risk

Much of the confusion about corrosion in municipal infrastructure may stem from how risk is addressed. Corrosion protection is simply a method of mitigating the risk of a pipe failure caused by corrosion. It is weighed against the cost of corrosion protection as it establishes a cost-benefit ratio for the protection. How one addresses the acceptable level of risk is the focus of this article. The authors will review six levels of corrosion protection that presently are in use for piping with metallic components (Table 1).

TABLE 1

CORROSION PROTECTION LEVELS FOR FERROUS PIPE MATERIALS

Level 1	No protection, pipe installed bare without monitoring system.
Level 2	Install pipe bare with loose PE encasement, without monitoring system.
Level 3	Add monitoring system (bonded joints and test leads) to Level 2.
Level 4	Bonded dielectric coatings or cement mortar coatings without monitoring system.
Level 5	Add monitoring system (bonded joints and test leads) to Level 4.
Level 6	Add CP to Level 5 or Level 3.[A]

[A]There currently is debate about the level of effectiveness of CP on loose film coatings.

Coatings & Linings

The majority of the steel pipe manufacturing industry has endorsed and written standards using corrosion Level 5 as the guideline for determining the best life-cycle cost-benefit acceptance criteria. There currently are 23 approved standards under the auspices of AWWA's Steel Pipe Committee. Of these standards, 14 deal with coatings and linings that are available for the protection of metallic pipe (Table 2). They vary from the earliest standard for coal tar enamel coatings and linings to the most recent fused polyethylene (PE) coating. The list includes cold-applied tape, fusion-bonded epoxy (FBE) coatings, paint systems for interior and exterior of pipe, extruded polyolefin coatings, petrolatum coatings, shrink sleeves for joints, cement mortar coating and lining, and polyurethane (PU) coatings and linings. Most of the dielectric coatings originally were used in the oil and gas industry. Many of the criteria for these coatings were established to meet the stringent requirements of those hazardous material pipelines.

TABLE 2

AWWA STANDARDS FOR COATING STEEL PIPE

AWWA C-203, "Coal-Tar Protective Linings and Coatings for Steel Water Pipelines—Enamel and Tape—Hot Applied"
AWWA C-205, "Cement-Mortar Protective Lining and Coating for Steel Water Pipe—Shop Applied"
AWWA C-209, "Cold Applied Tape Coatings for the Exterior of Special Sections, Connections, and Fittings for Steel Water Pipelines"
AWWA C-210, "Liquid-Epoxy Coating Systems for the Interior and Exterior of Steel Pipelines"
AWWA C-213, "Fusion-Bonded Epoxy Coating for the Interior and Exterior of Steel Water Pipelines"
AWWA C-214, "Tape Coating Systems for the Exterior of Steel Water Pipelines"
AWWA C-215, "Extruded Polyolefin Coatings for the Exterior of Steel Water Pipelines"
AWWA C-216, "Heat-Shrinkable Cross-Linked Polyolefin Coatings for the Exterior of Special Sections, Connections, and Fittings for Steel Water Pipelines"
AWWA C-217, "Cold-Applied Petrolatum Tape and Petroleum Wax Tape Coatings for the Exterior of Special Sections, Connections, and Fittings for Buried or Submerged Steel Water Pipelines"
AWWA C-218, "Coating the Exterior of Aboveground Steel Water Pipelines and Fittings"
AWWA C-222, "Polyurethane Coatings for the Interior and Exterior of Steel Water Pipelines"
AWWA C-224, "Two-Layer Nylon-11-Based Polyamide Coating System for the Interior and Exterior of Steel Water Pipe, Connections, Fittings, and Special Sections"
AWWA C-225, "Fused Polyolefin Coatings for the Exterior of Steel Water Pipelines"
AWWA C-602, "Standard for Cement-Mortar Lining of Water Pipelines in Place"

In the development of the dielectric coating standards, consideration is given to dielectric strength, adhesion, cathodic disbondment, handling, holidays, field procedures, and materials and repair of damage to the coatings. These considerations are given so that the risk of corrosion failure is diminished, if not eliminated. Similar consideration is given to the integrity of cement mortar coatings and linings. Levels of strength, water-soluble chloride ions, cement mixture, and water content all are part of the AWWA C-205[2] requirements. The thickness of the cement mortar lining for 24-in. (61-cm)-diameter pipe is 3/8 in. (0.95 cm) with pipe >36-in. (91-cm) going to

TABLE 3

SELECTED REQUIREMENTS OF COATING AND LINING QUALITY ASSURANCES

AWWA Standard	Thickness	Adhesion	Adsorption	Holiday Test	Date
C-203	3/32 in. (2.38 mm)	Pull test	N/A	Required	1940
C-210	16 mils (0.41 mm)	400 lb/in.^{2}	Vapor transfer	NACE Standard RP0188[4]	1978
C-213	12 mils (0.3 mm)	Knife test	N/A	NACE Standard RP0490[5]	1979
C-214	50-80 mils (1.3-2 mm)	200 ozf/in. wide	0.2%	6,000 V min.	1983
C-215	49-69 mils (1.2-1.8 mm)	N/A	0.2%	NACE Standard RP0274[6]	1988
C-216	40-60 mils (1-1.5 mm)	8 lb/linear in.	Vapor transfer	Required	1989
C-217	40 mils	N/A	Vapor transfer	N/A	1990
C-218	3.5-14 mils (0.09-0.36 mm)	V cut	N/A	N/A	1991
C-222	20-25 mils (0.51-0.63 mm)	750-2,000 psi (5-14 MPa)	3.0%	NACE Standard RP0188	1999
C-224	24-40 mils (0.6-1 mm)	2,000 psi	2.7%	NACE Standard RP0188	2001
C-225	50-75 mils (1.3-1.9 mm)	32 lb ft/in. wide	0.2%	NACE Standard RP0188	2003

1/2-in. (1.3-cm) thickness. Bonded joints normally are recommended.

The dielectric coating standards were requested and written as new materials were developed. All have special uses that affect the risk factors that might be considered in corrosion protection. Some coatings have better dielectric strength while others are more abrasion-resistant. Some coatings are made specifically for fittings while others are for aboveground service. Costs will differ for many of these products as they hinge on diameter, end use, and protection needs—specifically transmission lines vs distribution lines.

The standards became complex as the materials diversified. Materials include coal tar enamels and epoxy, polyolyfin (extruded, cross-linked, and fused), PU, petrolatum wax and tape, and nylon polyamides. Each requires different methods of application and inspection. All of the dielectric coatings listed above have some things in common as each requires at least a NACE No. 3/SSPC SP-6[3] blast cleaning. The confusion lies in the numerous alternative testing requirements, some of which Table 3 highlights.

What is the sufficient level of thickness? What is the correct adhesion? Which test method and value are appropriate answers to each of these questions depend on what level of risk is acceptable. The values in Table 3 were written so that the products would be roughly equivalent. They differ because the inherent natures of the products differ. The guideline used to write the standards assumed that the owner would specify either Level 5 or Level 6 corrosion protection—a reminder that most dielectric standards originated in the oil and gas industry.

Differences Between Metallic Pipe Manufacturers

Are the metallic water pipe manufacturers helping to eliminate the uncertainty surrounding water/sewage corrosion control, or are they helping to exacerbate it? The two major metallic pipe manufacturer segments for water pipelines—steel and ductile iron (DI)—have different views. Although it has been documented that steel and DI corrode at the same rate in the same soil,[7-8] the industries have written standards that follow different paths. Much of the confusion may be in the different methods that the two industries employ when considering corrosion protection and its cost benefit.

The DI pipe industry has promoted Level 2 corrosion protection as the corrosion level with the best cost-benefit ratio. The only approved AWWA coating standards for DI are AWWA C-104[9] for cement mortar lining, AWWA C-105[10] for PE encasement, and AWWA C-116[11] for FBE fittings. AWWA design manual M-41[12] states: "Joint bonding of ductile iron pipelines is generally discouraged except in cases where electrical continuity is needed for corrosion monitors and cathodic protection." It also states: "Although cathodic protection can be applied to ductile iron pipe, it is seldom cost effective." In a more recent development, the Ductile Iron Pipe Research Association (DIPRA) (Birminghan, Alabama) announced that its members—the eight leading DI manufacturers in North America—no longer will honor a warranty for DI pipe with any exterior dielectric coating other than PE encasement.[13]

AWWA C-105 contains requirements for thicknesses of 4 or 8 mils (0.10 or 0.20 mm), dielectric strength, and tensile strength. The standard also states: "The polyethylene encasement shall prevent contact between the pipe and the surrounding backfill and bedding material but is not intended to be a completely airtight or watertight enclosure." AWWA C-104 for cement mortar lining of DI pipe requires a thickness of 3/32 in. (0.24 cm) for 24-in.-diameter pipe and 1/8 in. (3 cm) for all larger sizes. Double lining can be requested. This is the same material as the steel pipe lining, which is a required 3/8-in. for 24-in.-diameter pipe and 1/2-in. thickness for all pipe over 36-in. diameter.

The reason for the divergence of thought processes about two similarly corroding materials may be found by considering the historical use for each. Steel pipe historically has been used in larger sizes (24 in. and larger) while DI pipe has had most of its market share in smaller sizes (36 in. and smaller). Studies have shown that CP costs have a life-cycle current rate of return of as much as 42 times the investment.[14] Also, it has been shown that diameter is one of the factors affecting rate of return. Such rates of return would affect the decision matrix regarding whether to protect the pipe or to leave it unprotected and replace it as it deteriorates and fails.

In a recent paper, Spickelmire[15] advances a decision matrix that includes risk factors for diameter and the critical nature of the pipeline. He proposes an expanded version of DIPRA's 10-point system, which includes numerous items with a 25-point threshold. The matrix is suitable for establishing a risk threshold. The decision to cathodically protect a 6-in. (15.2-cm) looped pipeline that serves 45 people vs a 60-in. (152.4-cm) pipeline that is a single-source pipeline to 12,000 people should consider the difference in risk levels.

AWWA M-27,[16] the organization's corrosion manual, is a compromise document that reflects the myriad philosophies within the pipe manufacturing industry. There are many instances in which an engineer, concerned about corrosion, will fill the interior voids at joints and apply a bonded joint material on steel pipe. However, that same engineer will allow the use of DI pipe with no interior filling and PE wrap as a substitute. Such a compromise promotes the continued separation of the steel and DI manufacturing communities. Corrosion may occur under any voids and introducing oxygen greatly increases the likelihood that a voided area will corrode.

The differing viewpoints leave the corrosion control community with a conundrum: how do they educate the utilities and engineering communities that, although the two philosophies are different, they fit together in a risk-based evaluation? Because steel and DI corrode in a similar manner in similar soils, it is the authors' opinion that both materials should be evaluated equally and be given the same level of corrosion protection.

The Cost of Corrosion Study states that education and lack of communication are the major obstacles to better implementation of corrosion technologies. Understanding the differences in the education many people are receiving may make the task easier. This article is an attempt to clarify some of the differences. The authors believe that it is the responsibility of all individuals in the corrosion industry to convince utilities and municipalities of the need to evaluate all metallic pipes equally. This educational process should include some procedure that takes into account the risk the owner deems acceptable on the specific pipeline being designed. In addition, it would include some evaluation of the expected life of the pipeline based on the level of protection given to the exterior surface of the chosen pipe product.

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