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CORROSION PROTECTION BY COATINGS FOR WATER AND WASTEWATER PIPELINES

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ABSTRACT

Corrosion protection by coatings for water and wastewater pipelines is the implementation of a well-balanced cycle of four equally important elements: specifying and using a proper coating system, proper surface preparation for the coating system, proper application of the coating system, and quality inspection of the coating system. This paper discusses the details of this concept, together with a comprehensive review on various coating systems and different surface preparation requirements for steel, ductile iron, and concrete pipes in water and wastewater applications.

Keywords: corrosion protection, coating, pipe coating, water and wastewater, pipe, pipeline

1. THE CYCLE OF CORROSION PROTECTION BY COATINGS

The proper use of protective coatings is the extremely effective means of preventing pipeline deterioration and corrosion leaks in water and wastewater applications. The function of a coating is to act as a barrier that prevents either chemical compounds or corrosion current from contacting a pipe substrate. The coating's effectiveness of fulfilling this function depends on its degree of integrity (being a completely continuous film or freedom from imperfection or defects), its ability to bond to the pipe substrate, and its ability to insulate against the passage of corrosion current (dielectric strength) or chemical ions[1].

Corrosion protection by coatings for water and wastewater pipelines is the implementation of a well-balanced cycle of the following four equally important elements:

a. Specifying and using a proper coating system
b. Proper surface preparation for the coating system
c. Proper application of the coating system
d. Quality inspection of the coating system

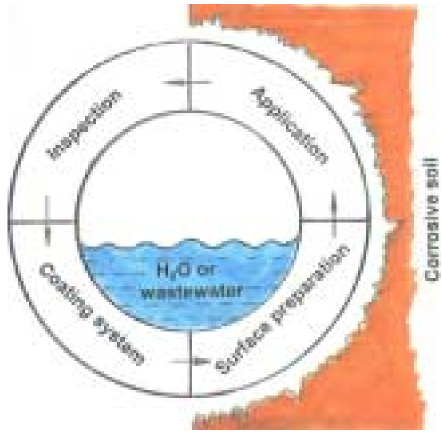

Figure 1 The corrosion protection cycle by coatings

The importance of specifying and using a proper coating system for a water/wastewater pipeline project cannot be overemphasized. While initial expenditures for properly engineered, high performance coating systems may seem high, this investment pays off in considerably reduced long-term maintenance and operation costs and also provides a peace of mind in protecting the environment as well as health and safety of workers. Once the best decision has been made on selection of the coating system, clearly defined specifications are required to communicate and execute the decision. Proper work is then carried out on surface preparation, shop and/or field coating application, handling and installation of coated pipeline. Finally, detailed specifications, application instructions, and the proper workmanship should be supported by thorough inspections to ensure the coating's effectiveness.

As to any specific pipeline project, it is essential to understand that corrosion protection provided by coating has a definite beginning and end. All the above four elements must work together to achieve the goal of proper protection. Failure of any of the four elements results in a failure of the project. To the entire water and wastewater industry, however, this cycle of corrosion protection by coatings shall be viewed as a continuous process of improvement, in which utility owners, specifying engineers and consultants, coatings manufacturers, pipe manufacturers, shop and field coating applicators, and general and subcontractors will work together continually in the execution of all the four elements.

2. PROPER SELECTION OF A PIPE COATING SYSTEM

For years, the water and wastewater industry has required a corrosion protective coating system that is able to withstand the corrosive environment heavily experienced by industrial and municipal pipelines both internally and externally. In order to meet this requirement, a corrosion protective coating system has to be able to meet three challenges below: environmental and safety regulations, the economics of each project, and high performance. Engineers must strike a balance between these three areas in refurbishing or designing new pipeline in water and wastewater application. The ideal corrosion protective coating system shall be environmentally friendly, work safe, durable and able to expose little or no metal/substrate surface to the environment, while also being resistant to environmental, mechanical and chemical damage from the initial stage of handling and installation to its entire service life. It should also come at a reasonable cost.[2]

As a result of the above requirements, the selection of a pipe coating system shall be based on careful considerations of the following attributes:

a. Handling and safety characteristics
b. Shop/field application and repair attributes
c. Surface preparation requirements
d. Physical performance requirements
e. Case histories
f. Cost analysis

2.1 Handling and safety characteristics

Handling and safety characteristics include mixing ratio, solids content, VOC, flammability, application methods, as well as whether the coating contains any hazardous ingredients such as coal tar, amines, solvents, and isocyanate monomers. Over the last ten years, compliance with rigorous regulations on volatile organic compound (VOC) emissions has become a must for any coating system. As a result, many low solids coatings such as solvent-based epoxies are pushed out from the coatings family for pipe coating in water and wastewater application. Requirements of OSHA, EPA, and FDA environmental and health standards have also played a significant role in eliminating or reducing the use of bituminous enamels and coal tar epoxies. In drinking water application, the toxicological properties of any lining system shall be certified to meet the requirements of rigorous standards (e.g. NSF 61 standard) for water safety.

The format of a coating also plays a role here; for instance, the mixing ratio of plural component coating systems. Plural component coatings with a mixing ratio higher than 1:1 will be more likely to cause mismetering problems (often called as off-ratio) during its application. The higher the ratio is, the higher the possibility it will occur. Furthermore, it is recommended to select those systems in which both components have the same or very close values of medium-ranged viscosities. When high or 100% solids coatings are being used more and more today, too high viscosity values of these coatings will cause application and equipment problems in handling.

2.2 Shop/field application and repair attributes

To ensure precise control of coating application and quality, many types of pipe coatings are applied in a plant or shop. The coating material must be suitable and properly applied to be effective in the shop application. This demands the establishment of a quality system in the shop in terms of application and inspection. It is therefore advisable to select such a coating that is backed by the technical and quality support of the coating's manufacturer.

A coating's ability to be quickly and efficiently applied and/or repaired in the factory or field is also an important attribute. A long cure time or an elaborate curing process can cause inefficiencies for shop and field applications. It is important to understand that shop-applied coatings may be damaged during shipping, handling, storage, or construction. It is often possible to field repair damaged coatings, but some shop-applied coatings cannot be repaired to their original quality.

Similar to the shop application and repair processes, the construction contractor's ability to achieve the proper results for field joint applications or field repair is very much limited by the number of coats and cure time required by the joint materials. A welded joint area is normally a weak spot in the steel pipe protection system, from the point of view of both mechanical and chemical failures. If the field applied joint corrosion protection system is the same as the shop applied material, proper application of the field applied joint corrosion protection material becomes the main concern of the corrosion specialist. Some coating systems require specific surface preparation methods, post application cure procedures, or application by trained and certified applicators. If one coating system is chosen over another on the basis of higher performance, the application of a field joint coating system that does not perform as well as the shop applied material is ill-advised.

Finally, for both shop and field applications, one should examine and select a coating system that can be properly applied under the specific shop or field environmental conditions such as humidity, ambient temperatures, dew point, etc. For example, if a pipeline project requires the pipes to be made and installed in a cold winter when ambient temperatures will be not more than 50^{o}F, one would not specify the use of epoxies.

2.3 Surface preparation requirements

Surface preparation is essential to the ability of the coating to bond to the pipe substrate. This bonding is important to eliminate the environmental fluid migration between the substrate and the pipe coating. It also assures permanence and ability to withstand handling during installation without losing effectiveness. It is therefore very important to understand the surface preparation requirements of the coating system to be selected. There is no shortcut here indeed, because poor surface preparation always results in poor bonding strength of the coating to the pipe. There have not been any results of long-term laboratory testing and actual field case histories which will approve the use of those so-called "surface tolerant" coating systems for pipeline applications. Detailed surface preparation requirements for various pipe substrates will be discussed in this paper later.

2.4 Physical performance requirements

There are many factors that should be considered when selecting a pipe coating in terms of physical performance; for example:

a. Type of soil and back fill[3]

Soil conditions and backfill of a proposed pipeline project influence the coating system selected and thickness specified. Soils may be rated by their corrosivity that includes resistivity, chemical contamination, pH, moisture content, and existence of stray electrical currents. Corrosive soil conditions demand a coating system that has the proper chemical resistance, high adhesion to the substrate, and low permeability, which can be measured by ASTM D714 /ASTM D543 / ASTM G20, ASTM D4541, and ASTM G9 / ASTM E96 / ASTM D570, respectively. Soils may also be rated by their shrink-swell factor (soil stress). High shrink-swell soils can damage conventional coatings. Ideally, trenches should be free of projections and rocks, permitting the coating to bear on a smooth surface. When backfilling, rocks and debris should not strike the pipe coating. The ability of a pipe coating to resist penetration if set on stones on the trench can be determined by: ASTM D 785, ASTM D5, and ASTM D2240. The resistance of a pipe coating against damage by rock in back fill can be evaluated by ASTM G 13 and ASTM G19.

b. The use of cathodic protection

If no cathodic protection is used together a pipe coating, the coating should be selected with the least amount of possible damage. This requires that the coating system selected not only meets the corrosion control needs, but also allows economical transportation, handling, storage, and pipeline construction with minimal coating damage or repair. In addition to the previous ASTM testing methods for measuring the resistance of the coating to soil stress and backfill, ASTM G14 impact resistance testing methods can be used to test the coating's ability to withstand damage due to a direct impact with another object. This test is also relevant for evaluation of internal lining systems due to its ability to predict good lining performance and resistance to damage[4].

In many cases, however, pipe coating is supplemented by cathodic protection. The two protective methods work synergistically: the coating greatly reduces costs of the cathodic protection system, while cathodic protection substantially extends the useful life of the coating. A coating used with cathodic protection must have good dielectric strength so that both cathodic protection potentials and current flows would not affect its ability to act as a corrosion protective barrier. Coatings with a low dielectric strength, or those that will allow some current flow, often allow the buildup of cathodic deposits on the surface or under the coating, causing coating breakdown. This is not an uncommon occurrence where coatings contain metallic pigments. ASTM D149 can be used to evaluate the dielectric strength of a coating.

It is also necessary for the coating to withstand cathodic disbondment. Experience in the oil and gas pipeline industry has clearly shown that coatings/linings with better cathodic disbondment resistance have better corrosion resistance and greater longevity. The coating/lining systems with good adhesion to the steel substrate tend to have a similar resistance to cathodic disbondment. If a coating/lining is able to adhere to the steel substrate, it will therefore tend to resist the undercutting damage of corrosion, thereby offering a longer service life. There are several standard testing methods which can be used, such as G95, G8, and CSA Z245.

c. Pipe installation methods and location[6-9]

Severe environments, such as river crossings, pipe inside casings, exceptionally corrosive, high soil stress areas and rocky conditions require special consideration on the performance of a selected pipe. Different installation methods also affect the coating selection. For instance, directional drilling requires the coating to exhibit a certain degree of flexibility, particularly when the construction and installation site has cold ambient temperatures. Some coating systems such as mastics, enamels, tapes, or epoxies may become brittle in freezing temperature. Another example is that, if the pipeline needs to bend during installation, it is necessary to ensure the flexibility of the selected coating. Flexibility is thus a good indicator of a coating’s ability to withstand the cracking, disbonding, or other mechanical damage of the coating/lining that can occur from handling and bending the steel pipe not only in the field but also in the factory. Flexibility of a coating can be evaluated by ASTM D522 / ASTM G10.

e. Corrosive environmental conditions[6-9]

The corrosive environmental conditions that a coating is going to be exposed to plays an important role in the coating selection; this is particularly true for internal lining applications. In the wastewater lining application, for example, resistance of a coating against microbiologically influenced corrosion (MIC) becomes more important than ever, thereby reducing the level of use of some poor performance lining systems such as cement-mortar.

In the industrial water area, higher flow rate and harsher environments also demand the better performance of all coating systems. For any pipeline internal lining application, the coating must be able to withstand the constant flow of liquid and any particulates. Normal municipal pipeline velocities are in the range of 8 to 16 feet per second (2 to 4 meters per second) but these rates can increase in some cases to over 30 feet per second. The corrosion protective coating must be capable of withstanding the constant abrasion caused by passing water at various velocities. One of the performance tests which can be used in this case is Taber abrasion resistance testing (ASTM D4060). Another accelerated test can be ASTM G6.

Impact of other environmental conditions on the coating selection includes the ability to withstand elevated operation temperature (ASTM G8, ASTM D870, and ASTM D2485) and the resistance to weathering if the pipe is being stored or used aboveground (ASTM G11 / ASTM G53).

2.5 Case histories

As a result of rigorous environmental VOC regulations and high performance requirements, many coatings manufacturers are in a rush to develop and launch new pipe coating systems. While the industry should appreciate the variable choices of coatings and coating suppliers, it is very important to select those coating systems and also coating suppliers that are backed by solid case histories in terms of both performance and also capability of plant/shop technical support.

2.6 Cost analysis

The true cost of any pipe coating system is not the 'cost per bucket' or even the applied cost per square feet or square meter. The true coating cost is the sum of ***Materials Cost + Application Cost + Maintenance Cost +Hidden Cost .*** This true cost should cover initial costs of coating but also installation, joint coatings and repairs.

An example of highlighting the impact of both materials cost and application cost on the total coating cost is to compare epoxy and 100% solids polyurethanes. The materials cost of 100% solids polyurethanes may be slightly higher than that of epoxy coatings. However, the application cost of 100% solids polyurethanes is substantially lower, because of its one coat application (less labor and faster completion time) versus multi-coat application of epoxy coatings.

While dealing with costs, maintenance costs and hidden costs cannot be avoided. Maintenance costs of a pipe coating project are related to the performance of the coating. High performance coatings, although normally having higher initial material costs, often cause lower maintenance costs. An example of the hidden costs is the pump efficiency, which is related to the water/wastewater flow efficiency. Because 100% solids polyurethane has better abrasive resistance and is smoother than cement-mortar lining, for example, the pump efficiency of pipes coated with the polyurethane is significantly higher than the case of cement-mortar. This is particularly true for large size diameter pipes, thereby reducing the operation cost.

3. COMMON PIPE COATING SYSTEMS FOR THE EXTERIOR AND/OR INTERIOR APPLICATION

The following describes some of the coating materials commonly used in the exterior and/or interior water and wastewater applications for steel, ductile iron, and concrete pipes. Other coating materials may have been used or may be developed. Each coating system has its own advantages and disadvantages. The user is encouraged to carefully refer to the manufacturer's recommendations and related specifications or standards, and then makes the best coating selection for the pipeline project based on the considerations discussed in Section 2 of this paper.

<u>3.1 Bituminous enamels</u>: Bituminous enamels are made from coal tar pitches or petroleum asphalt. Natural asphalts, such as gilsonite, are sometimes used as well in combination with petroleum asphalts to enhance physical properties. AWWA C203 describes the material and application requirements for shop-applied coal tar protective coatings for steel water pipelines intended for use under normal conditions when temperature of the water in the pipe will not exceed 90°F (32°C)[10]. The standard covers coal tar enamel applied to both exterior and interior of pipe, special sections, connections, and fittings; it also covers hot-applied coal tar tape applied to the exterior of special sections, connections, and fittings. Coal tar enamel is probably the oldest of all types of protective coatings and this coating is available to all sizes of pipe. It is applied over a coal tar or synthetic primer. Coal-tar enamel may be used on the exterior of steel pipelines with or without incorporating bonded asbestos-felt and fiberglass mat to reinforce and shield the coal-tar enamel. The applied external coating is usually finished with either a coat of whitewash or a singe wrap of kraft paper. Internally, the coal-tar enamel is used without reinforcement or shielding. The enamel is applied to the interior of pipe by revolving the pipe, inserting a lance and distributing the liquid coal tar lengthwise through the revolving pipe. The application of coal tar enamels to joints in the field is usually by daubing. This is the use of long handled brushes dipped into the molten coal tar and spread over the surface to be protected. Exterior joints may be daubed, but are more often poured, using a diaper that allows the hot-applied coal tar to flow around the pipe and over the joints.

The application of asphalt as a 100% solids hot-melt coating is very similar to that with coal tar. The major differences between coal tar and asphalt are the excellent water resistance of coal tar and the relatively good weather resistance of asphalt. As a result, the asphaltic materials are used more for exterior application. Over the past decade, the use of bituminous enamels has been significantly declined, mostly because of the hazardous nature of the bituminous materials due to OSHA, EPA, FDA, and NSF environmental and health standards.

<u>Combination sprayed zinc/sprayed bituminous coatings</u> are the most commonly used coatings for protection of the exterior of ductile iron pipe in Europe and other parts of the world. This coating system is available to all sizes of pipe. The application methods for the external sprayed zinc/bituminous coatings are covered in various standards including ISO 8179[11]. Thin bituminous enamels, normally applied at the foundry, were first used in

the mid-1960's to obtain a marginal improvement in the corrosion performance of buried spun-cast ductile iron pipes. However, by the late 1970's, it was reported that an increasing incidence of through-wall corrosion was evident on thin-walled ductile iron pipe that had been supplied bearing a thin bituminous coating, intended primarily to improve the surface appearance of the pipes during storage, rather than for in-service corrosion mitigation. This development led to the introduction of a flash of zinc spray, which was applied before the bituminous enamel to impart a notional degree of sacrificial protection. During the early 1980's, the thickness of the zinc spray coating was increased in stages as the limited capability of a few microns of zinc to provide an effective corrosion prevention barrier over the lifetime of a water main was increasingly doubted. Thick coatings increased the cost of zinc consumed. Additionally, increased handling requirements and processing stages added to production costs. In an attempt to overcome the inadequacies of three poor coating methods, it is not uncommon now to find that sprayed zinc/bituminous coating and loose polyethylene encasement are applied together to ductile iron pipes. Various experimental studies and case histories, however, have indicated that the thin (about 50-70 microns or 2-3 mils) sprayed zinc/bituminous coating approach offers at best only a marginal enhancement of short-term corrosion protection for ductile iron pipes.

Currently in North America, unless otherwise specified, a bituminous coating (mostly asphaltic) with or without sprayed zinc will be applied to the outside of all ductile iron pipe and fittings. For some reason, the use of metallized zinc exterior coating is not marketed in the United States. As a result, the combination sprayed zinc/asphaltic coatings are only applied in the United States on ductile iron pipe for use outside the United States. The primary purpose of this asphaltic coating thus becomes to minimize atmospheric oxidation for aesthetic reasons prior to burial. Corrosion protection of exterior ductile iron pipe and fittings is normally applied with the polyethylene encasement method as recommended by the ductile iron industry in the U.S.[5]

<u>Cold-applied tape coatings</u> are used for the exterior of steel pipes but are strongly discouraged by the ductile iron industry for protecting ductile iron pipe. AWWA C209 covers the manual application of a cold primer and cold-applied tape on the exterior of special sections, connections, and fittings for steel water pipelines installed underground in any soil under normal or average conditions[12]. AWWA C214 covers the materials, the systems, and the application requirements for prefabricated cold-applied tapes for the exterior of steel pipe placed by mechanical means[13]. Tapes with both polyvinyl chloride and polyethylene backing are listed. For normal conditions, prefabricated cold-applied tapes are applied as a three-layer system consisting of primer, corrosion preventive tape (inner tape), and a mechanical protective tape (outer tape). This system is available on 2" through 120" O.D. pipe and is normally recommended for temperatures up to 140^{o}F (60^{o}C), but tapes capable of higher service temperatures (up to 210^{o}F or 99^{o}C) are also available. Cold-applied, multi-layered tape systems are designed for plant coating operations. Coated pipes should be handled carefully to protect pipe and coating from damage. Over the trench, field-applied tapes may be applied with tape wrapping machines. Tape coatings applied over the ditch are less susceptible to damage due to reduced handling, but their performance can be more affected by variations in ambient

temperatures and humidity as well as by less adequate field surface preparation. The thickness of the tape coating system varies; however, all tapes shall be sufficiently overlapped to meet performance requirements. If severe construction or soil conditions exist where mechanical damage may occur, a suitable overwrap of an extra thickness of tape is required.

Fusion-bonded epoxy coatings are mostly used in oil and gas pipeline applications, but are also used somewhat in waste and wastewater applications as well; for example, pipes and fittings for steel and fittings for ductile iron. AWWA C213 describes the material and application requirements for fusion-based epoxy coatings for the interior and exterior of steel water pipe, special sections, welded joints, connections, and fittings of steel water pipelines installed underground or underwater under normal construction conditions[14]. These coatings are applied to preheated pipe surfaces 400°F to 500°F (204°C to 260°C) in a 12 to 25 mil thickness, with or without primers. If primer is required, there are minimum-maximum overcoat times. The coatings are available in ¾” to 43” (1.9 cm to 122 cm) O.D. pipe. In potable water systems, operating temperatures up to 140°F (60°C) are recommended for the powder epoxy coatings. Except for welded field joints, fusion-bonded epoxies are plant/shop applied to preheated pipe, special sections, connections, and fittings using fluid bed, air, or electrostatic spray. Due to their lack of thickness to cover up apparent metallic substrate defects, the power epoxy coatings permit excellent inspection of the substrate surface before and after coating. A heat-bondable polymeric hot melt patch stick repairs pipe needing repair due to hackles, coating imperfections and other defects. A 100% solids liquid epoxy repair material is recommended within 12” of each end of pipe. Powder coating manufacturers will also make recommendations for field repair materials and application procedures. Fusion-bonded epoxy for ductile iron fittings is furnished in accordance with AWWA C116[15]. It is not used for ductile iron pipe because the thin-film coating system cannot achieve a holiday-free surface to cover the surface roughness normally associated with ductile iron.

Liquid Epoxy Coatings have many different types: some are solvent-based and others are 100% solids; some are heat cured and others are chemically cured. The curing agent may be an amine, amine adduct or polyamide; and the epoxy may be modified with coal tar, phenolic, fly ashes, or other modifiers. AWWA C210 describes liquid, chemically cured epoxies for the interior and exterior of steel water pipe, fittings, and special sections installed underground or underwater[16]. AWWA recommends the use of these coatings in water service systems at temperatures up to 140°F (60°C). The liquid epoxy system described in AWWA C210 differs from the customary product commercially available in that it has a very high flexibility, elongation, and impact resistance. Any liquid epoxy for water utility purposes must meet the requirements of AWWA C210. Liquid epoxy is not used for the exterior of ductile iron, because the rough surface is not suitable to be covered by the slow multiple coat application of the coating.

Solvent-based epoxies were commonly used before as an alternative coating system to cement-mortar in potable water applications for steel pipe. The use of these low solids, solvent-based epoxies has recently declined due to the problems involved with the use of solvents and VOC air pollution. As a result, the solvent-based epoxies are being replaced by 100% solids rigid polyurethane and high solids or solventless epoxies.

Liquid coal-tar epoxy coatings have been used as an internal lining system for wastewater or non-potable water pipes of all the three substrates: steel, ductile iron, and concrete. In the case of ductile iron, the coal-tar epoxy used as an internal lining only is often added with at least 20% of fly ash power (so-called ceramic powder). The combination of both the epoxy and coal-tar combines the good properties of the two materials to form a good water and saltwater-resistant coating. Some coal-tar epoxies become brittle when exposed to sunlight and some also have very poor adhesion to the substrate[5, 7].

<u>Cement-mortar</u> is normally composed of Portland cement, sand, and water, well mixed and of the proper consistency to obtain a dense, homogenous layer. It has the longest history of protecting steel and ductile or gray cast iron. Today, the main use of the cement-mortar material for pipeline is as an internal lining for potable water application, although sometimes it is still used for exterior as well; for example, steel pipe. Special cement lining materials may be available for special service requirements (e.g. weak mine acids, some industrial recycled water and certain other chemical liquid wastes). Pipe surfaces covered with cement-mortar are protected by the alkaline cement environment, which passivates the steel or wrought iron and thus prevents corrosion in most natural environments. Internally, the cement mortar is centrifugally compacted to remove excess water and produce a smooth, uniform surface. Externally, the coating is a reinforced cement mortar, pneumatically or mechanically applied to the pipe surface. AWWA C205 describes the material and application requirements for steel water pipe by shop application of cement mortar[17]. AWWA C602 describes the materials and application processes for the cement-mortar lining of steel pipeline in place, covering both newly installed pipes and older pipelines[18]. Cement-mortar lining for ductile iron pipe and ductile iron and gray iron fittings for water service is in accordance with AWWA C104[19]. The cement-mortar lining is satisfactory for temperatures up to 212^{o}F. Sometimes an asphaltic seal coat is furnished. In this case, the lining is only adequate for temperatures up to 150^{o}F.

<u>Heat shrink sleeve</u> products have been recently used as a corrosion protection method to protect field-welded joints or special connections of steel pipeline, being an alternative to cold-applied tape as well as spray-applied epoxy, coal tar, and polyurethane. The heat shrink sleeve consists of a cross-linked and pre-stretched sheet which, upon heating, will shrink to its original length. This sheet is coated with a protective heat-sensitive adhesive. When heat is applied to the sleeve wrapped around a joint, the adhesive melts and becomes a liquid, while the sleeve backing begins to shrink. The radial shrinking forces of the sleeve squeezes the fluid adhesive into all of the pipe surface irregularities, while the sleeve conforms tightly to the joint profile. On cooling, the adhesive solidifies, effecting a tough bond to the pipe and the pipe coating. The sleeve adhesive achieves the corrosion protection by preventing moisture and air ingress to the pipe surface. The outside Polyolefin backing mechanically protects the adhesive and the joint. The adhesive further acts to hold and anchor the backing around the joint through adhesion to the substrate and the backing. The heat shrink sleeve method is accepted in the industry

because of its design flexibility and compatibility with pipeline conditions. It is suggested to carefully select and use the proper sleeve products based on different pipeline conditions and also pay attention to the compatibility of the sleeves with pipe coatings. AWWA C216 covers the material and application requirements of heat-shrinkable cross-linked polyolefin coatings for the exterior of special sections, connections, and fittings for steel water pipelines[20].

Polyethylene Encasement Polyethylene encasement is not a true coating per se, because it does not bond to the substrate, neither is it completely sealed. It is a standard corrosion control method specifically and favorably recommended by the U.S. ductile iron industry, and sometimes it is promoted as the only method needed to control corrosion for all external ductile iron and cast iron pipelines in the United States. Since its first use in operating water systems in Lafourche Parish, Louisiana, and Philadelphia by the late 1950's, polyethylene encasement has been taken in various standards in the United States and then in other countries such as Japan (JDPA Z2005), UK (BS 6076), Germany (DIN 30674), France (AFNOR NFA 48-851), and an international ISO standard (ISO 8180). In 1972, the first standard for polyethylene encasement was adopted as AWWA C105. In 1993, the standards were revised to allow the use of either the 8-mil (200 microns) low-density polyethylene or 4-mil (100 microns) high-density cross-laminated polyethylene film, and a recommendation was added that in wet conditions the polyethylene encasement should be taped every two feet around the pipe circumference. In 1999, the standards were revised again to replace low-density polyethylene with linear low-density, and soil resistivity ranges were modified to make the procedure more conservative. An additional paragraph was added that acknowledged that other corrosion control methods besides polyethylene encasement may be required in certain circumstances[21].

Advantages on polyethylene encasement include that: it is relatively inexpensive, easy to install, does not require maintenance or monitoring, and is easy to repair if damaged. An objection to the use of polyethylene encasement is that the polyethylene films restrict the subsequent use of cathodic protection. Another is that the encasement is easily damaged, resulting in holidays, rips, or tears. These defects are easily created during handling, and during pipe laying and backfilling operations. Such defects may admit environmental water into the interface between the films and pipe surface, leading accelerated attack to the pipe in the vicinity of these defects.

There is a wide range of controversy over the use and success of polyethylene encasement as a successful corrosion control method[22]. On the one hand, there are studies conducted by DIPRA and its member manufacturers, indicating the long-term effectiveness of this method on the corrosion protection of ductile and gray cast iron pipes. Some thus conclude that "the number of documented failures of polyethylene encased pipelines- the vast majority of which are the result of improper installation – is insignificant compared to the number of miles of cast and ductile iron pipe that are afforded excellent protection with this method of corrosion prevention". On the other hand, there are also reports from different utilities and corrosion consultants which document corrosion problems under both damaged and undamaged polyethylene encasement. Some utilities and corrosion therefore only allow the use of polyethylene encasement in certain conditions and in most corrosive conditions require tight bonded coatings and cathodic protection for ductile iron. Polyethylene encasement is not recommended by DIPRA as the sole protection method where high-density stray currents may be present[23]. It was also suggested that polyethylene wrapping might not provide enough protection in continuously saturated soils, although it might be used in conjunction with cathodic protection systems[24]. Polyethylene also exhibits significant softening at temperatures over 82^{o}C (180^{o}F) and will melt around 104 to 110^{o}C (220 to 230^{o}F).

"T Lock" plastic coatings are used in the interior of concrete sewer pipelines as an alternative to spray applied coating systems such as bituminous coatings, coal-tar epoxies, liquid epoxies, vinyl coatings, and chlorinated rubber coatings[5]. Many of these coatings have been applied to concrete sewer pipelines. Almost all have resulted in a complete failure. It is generally believed that any coating that would withstand sulfuric acid would be suitable for the lining application of concrete sewer pipelines. Unfortunately, because of the nature of the concrete, such coatings are subject to imperfections, and even a minute imperfection will cause the concrete to disintegrate under the coating, pushing it from the area of imperfections. Another problem is that concrete pipes are buried and are thus subject to earth movement. Where movement occurs, some cracking of both the concrete substrate and the coating, particularly at the joint area, may also occur, which opens the concrete to immediate attack. As an alternative, a cast-in-place molded or extruded plastic lining that could be heat welded to itself is formed with "T" extensions on the back of the sheet to hold the sheet in physical contact with the concrete. The plastic sheet lining is formed into sheets of the size required by heat welding the sheet together. The sheets are then placed on the form and the concrete poured in a normal fashion. The use of "T Lock" plastic lining has resulted in some degree of success; however, it has not been a complete solution to the corrosion protection of concrete sewer pipeline. It is labor intensive, easily damaged, and difficult to repair.

100% solids rigid polyurethane coatings: Over the past ten years, there has been a movement towards the development and use of proper high-performance 100% solids rigid polyurethane coatings for corrosion protection of all three pipe substrates: steel, ductile iron, and concrete. The specially designed plural component and zero VOC polyurethane (PU) coatings have been demonstrated to be by far the most successful protective coating systems used for both exterior and interior applications. These polyurethane coatings have excellent adhesion to steel, ductile iron or concrete, combined with excellent chemical resistance, impact resistance, resistance to cathodic disbondment, and abrasion resistance. The fast setting (drying) nature of the 100% solids polyurethane coatings also means that they are very suitable for rapid application lines during pipe production, and they can be applied to any film thickness at virtually any ambient temperatures. The success of the 100% solids polyurethane coatings on steel, ductile iron and concrete pipes has been confirmed in water and wastewater distribution systems already in service in North America, the Middle East, several European countries (in particular, in France), and very recently, in a number of Asian countries. The polyurethane coatings have also been used successfully in conjunction with cathodic protection systems for protecting ductile iron and steel pipes, where the function of the coatings is both to improve degree of protection and also to reduce the capacity of the cathodic protection installation required to achieve complete immunity from corrosion attack. The most recent AWWA C222 describes the material and application requirements of 100% solids rigid polyurethane coatings for the interior and exterior of steel water pipe, fittings, and special sections[25]. Ductile iron pipe manufacturers and their coating applicators have also established internal specifications for both shop and field application of 100% solids rigid polyurethanes. The polyurethane coatings have been used in the United States on ductile iron pipe and fittings both as an internal and external coating since 1988, with numerous successful case histories. These polyurethane coatings are available for steel and ductile iron pipe size of 4” and above. In the interior application of concrete sewer pipeline, good results are achieved with 100% solids polyurethanes if the concrete surface is dry, clean, and free of any visible bug holes or cracks. Otherwise, suitable rendering materials such as an epoxy-polyurethane hybrid render are manually applied before the 100% solids polyurethane is sprayed, providing a holiday-free coating film for corrosion resistance.

Recent developments in the 100% solids polyurethane coatings technology have resulted in two innovations from which the water and wastewater industry can particularly benefit. One innovation involves the development of a protective lining that incorporates anti-microbial additives. There are two commonly used methods for protecting wastewater structures from corrosion. The most common method is the use of a membrane or barrier between the structure and its corrosive environment. 100% solids rigid polyurethane coatings have been used for this purpose for years because of their flexibility, adhesion, inertness, and their resistance to abrasion and chemical attack. A second and newly established protection method involves altering the characteristics of the environment to diminish or eliminate the corrosive environment. With the anti-microbial modification, the 100% solids rigid polyurethane linings offer long-term corrosion protection by modifying the environment while protecting the substrate.

While 100% solids rigid polyurethanes feature superior abrasion resistance, applications involving extremely high flow rates and unusually abrasive instances demand something more. Newly developed ceramic modified coatings are engineered to meet the challenge of highly abrasive or high flow applications, offering unbelievable durability, impact, corrosion, and chemical resistance[2].

4. PROPER SURFACE PREPARATION FOR STEEL, DUCTILE IRON, AND CONCRETE PIPES

Because of the multiplicity and complexity of coating systems and their different surface preparation requirements, selected coatings for a pipeline project shall be applied on a pipe surface that has been prepared according to the coating manufacturer’s recommendations and applicable standards or specifications. These surface preparation recommendations shall cover the needs of surface for shop coating application, inspection, repairs and field coating application. The following are some general areas that shall be addressed for each of the three pipe substrates: steel, ductile iron, and concrete.

4.1 Surface preparation for steel pipes

Plant/Shop steel pipe surface preparation

a. *Cleaning prior to abrasive blasting*. It is important to understand that ordinary abrasive blast cleaning techniques do not remove visible and non-visible contaminants such as oil, grease, or other soluble contaminants. Surfaces to be abrasive blast cleaned shall therefore be inspected accordingly and, if required, to remove these contaminants by cleaning in accordance with a proper method such as SSPC-SP1[26]. If solvent is used for this cleaning purpose, only solvents that do not leave a residue shall be used. Previously coated surfaces can be cleaned by hand or with power tools to remove loose coating. Solvent cleaning may be needed as well to remove non-reacted or uncured coating resin. Preheating to remove water and ice may be used provided that the pipe is preheated in a uniform manner to avoid distortion of the pipe. Surface imperfections such as burrs, gouges, and weld spatter shall be removed by filing or grinding to prevent holidays in the applied coating.

b. *Minimum abrasive blast cleaning*. Steel pipe coming directly from the mill is usually abrasive blast cleaned by means of a production line centrifugal wheel machine. Manual abrasive blast cleaning is normally used for fittings, special connections and local repair. Most coating manufacturers recommend a degree of cleanliness and a minimum blast profile for good coating adhesion. Generally, all steel pipe exterior surfaces have been recommended to achieve at least an SSPC-SP 6/NACE No. 3[27] Commercial Blast finish for coal-tar enamels, asphalt coatings, tape coatings, or an SSPC-SP 10/NACE No. 2 Near White finish[28] for most other liquid or powder coatings such as fusion-bonded epoxy, liquid epoxy, and polyurethane. For interior lining application, an SSPC-SP 10/NACE No. 2 Near White finish or an SSPC-SP 5/NACE No.1 White finish[29] is normally required for most coatings. A minimum angular profile (anchor pattern) is also normally recommended with the finish. For extensive cleaning of a previously coated surface in shop repair application, abrasive cleaning can be either all the way down to the steel to completely remove the existing coating, or brush-off blasted to create a rough texture on the existing coating surface to accept a new coating as per SSPC-SP 7/NACE No. 4[30]. This decision is made normally depending on the conditions of the previous coating and the coating's manufacturer shall be consulted. If a greater degree of surface preparation is recommended by the manufacturer or is required for the coating to meet the requirements, that level of surface preparation shall be used. The abrasive material shall be proper angular media made of slag, steel, sand, or mineral. Non-angular blasting media will generally not provide an adequate surface anchor pattern and its use should therefore be discouraged. Abrasive blast cleaning shall be performed when the metal temperature is more than 5°F (3°C) above the dew point using clean, dry, oil-free air. Proper blasting machine setup and also proper blasting media mixing are important to achieve the adequate blasting finish and angular profile.

c. *Finish appearance*. Cautions shall be made in an attempt to achieve a “near white” or “white metal” finish. The appearance of such a finish is affected by the type of abrasive used, the type and condition of the steel being blasted, environmental conditions before and after blasting, whether it is observed in natural lighting or artificial lighting, and the total lighting available. When keeping the minimum abrasive blast cleaning in mind, the user shall pay attention to not over-blasting the surface with inadequate machine setup and blasting media mixing.

d. *Dust clean*. Surface preparation shall not be considered complete until the dust or abrasive particles that may remain lodged in and on the surface have been removed from the blasted surface. Clean, dry, oil-free compressed air shall be used to blow the dust, grit, or other foreign matter from the blasted substrate in a manner that does not affect the cleaned surface, other cleaned pipe, or pipe to be coated. Vacuum cleaning or other methods may be used in place of compressed air.

e. *Surface inspection*. The cleaned interior and exterior surfaces of pipe shall be inspected to ensure conformity of adequate surface preparation. Surface imperfections such as burrs, gouges, and weld spatter shall be removed by filing or grinding to prevent holidays in the coating and shall be abrasive blast cleaned where applicable.

f. *Post-blasted protection from moisture and contaminants*. Blast-cleaned pipe surfaces shall be protected from condensation, moisture, rainfall, frost, and snow. Blast-cleaned surfaces shall also be protected from other contaminants, including sand, grit and dirt. The blasted pipe surface shall not be allowed to flash rust or exhibit deterioration before coating. It is generally recommended to blast only as many pipes as can be coated the same day or in the same shift.

<u>Field steel pipe/joint/repair surface preparation</u>

Most steel pipes installed today are plant/shop coated first and then delivered for field welding joints and/or installation. If field joints are to be welded, the main line coating is normally cutback at the time of its application to produce approximately several inches of bare steel on either side of future weld. On large projects in remote areas, the economics may favor a railhead or field coating site. Field coating application is also needed for the field welded joint and repairing purpose.

The general principles of surface preparation requirements outlined in plant/shop steel pipe application shall be followed in the field application as well. Additional areas that should be addressed include:

a. *Environmental conditions*: Ensure that the temperature of the steel surface is more than 5 degrees above the dew point and that the relative humidity is not more than 85%. Dehumidification may be needed depending on the environmental conditions.

This is particularly true for internal field lining and field welded joint applications. The steel area may be isolated and heated in order to remove moisture, water and ice, provided it is done in a uniform manner to avoid distortion of the pipe.

b. *Surface cleanness and salt contamination*: It is important to pay more attention to the surface cleanliness and salt contamination of field steel surface than plant/shop application where new steel from the mill is freshly used. Tests may be conducted in order to ensure that the surface is not contaminated with salt. There have been no thorough studies done to determine the recommended acceptable levels of salt contamination and their impact on long-term pipe coating performance. Coating manufacturers should be consulted; an example is given in the table below.

Service Type	**Chloride**	**Soluble ferrous ions**	**Sulfate**
Lining application	Less than 3 μg/cm^2	Less than 6 μg/cm^2	Less than 8 μg/cm^2
Exterior wet/dry or sub-immersion	Less than 5 μg/cm^2	Less than 8 μg/cm^2	Less than 10 μg/cm^2
Atmospheric service	Less than 7 μg/cm^2	Less than 10 μg/cm^2	Less than 17 μg/cm^2

High pressure water cleaning and the use of suitable solvents or other cleaners may be used to remove salt contamination, oil, and grease on the field steel surface. However, only solvents/cleaners that do not leave a residue shall be used; otherwise, the residue shall be removed.

When primers are used that must dry before coating is applied, all moisture, dust, and dirt must be removed from the primer surface before coating.

c. *Surface preparation methods* Most modern field practices use abrasive blast cleaning as a method for steel pipe, large joint, and large repair surface preparation. Sandblast cleaning can be the least expensive method of field surface preparation, especially if sophisticated equipment is used. In removing coatings to make tie-ins, caution should be taken to ensure that the surface preparation method used for preparing the overlay area onto the factory-applied coating is creating the required surface profile in the coating and not removing the factory-applied coating.

If sandblasting is not practical or the area of the repair is too small to blast, a secondary method of surface preparation, either by hand sanding or power tool cleaning, is acceptable. Power tool cleaning should be completed with an aggressive method thereby ensuring that the required surface profile is being created. Wire-wheel or manually sanding of the steel surface is unlikely to create the necessary profile or depth in the steel surface and is therefore not recommended. The use of the power tool cleaning will only be allowed to the pipeline when accessing of sandblasting equipment is not possible. It is important to ensure that the hand and power tool cleaning application provides the same minimum surface finish and profile required for plant/shop applications.

4.2 Surface preparation for ductile iron pipes

There is a significant difference between a smooth steel surface and a ductile or cast iron surface and therefore surface preparation procedure for coating ductile/cast iron pipe shall be modified or specified accordingly. Surface conditions of ductile or cast iron materials vary significantly from one manufacturer to another, and they also depend on pipe size, process, and batch. Compared with smooth steel surfaces, surfaces of ductile or cast iron are normally much rougher, covered with burrs, slag (iron oxide), scruff, and other protuberances, pits and holes, mold coating, rust staining, thick, tightly adhered or loose annealing oxide.

To address the different surface conditions on ductile or cast iron and thus the surface preparation requirements for interior and exterior coatings, U.S. Pipe had developed, in the early 1980’s, surface preparation specifications for U.S. Pipe ductile iron products to receive special coatings. The surface preparation specifications were basically modifications of the SSPC Surface Preparation Guideline for steel surface. Since then, modifications have been made several times by DIRPA on the U.S. Pipe’s specifications to develop a surface preparation standard for the ductile iron industry. As a result, a new standard (NAPF 500-03) was issued in March 2000 by the National Association of Pipe Fabricators. Although the SSPC guidelines are generally followed, the new standard provides limited specific requirements on the amount of surface preparation required for ductile iron surface and depends more on the coating manufacturer and pipe manufacturer for specific recommendations. Unlike the case that SSPC standards require the removal of all oxide layers or mill scale from steel (SSPC – SP 5, 6, and 10), this new NAPF standard allows the different degrees of the removal of tightly annealing oxide and rust staining from ductile iron pipe and fittings.

The general principles of surface preparation requirements for steel pipe application shall be followed for ductile iron as well. All ductile iron pipe and fittings shall be delivered to the coating application facility without asphalt, which is not compatible with top coatings, or any other coating on the interior and/or exterior surfaces prior to the application of the specified lining/coating materials. The ductile iron surfaces to be lined/coated shall be blast-cleaned to achieve a surface anchor pattern with a profile of 2.5 mils or greater. Less degrees of the surface angular profile may be recommended by some coating manufacturers in the lining application, however, the adhesion of some of those types of coatings to ductile iron is often poor regardless of the level of surface preparation. Blasting with an angular abrasive media such as slag, sand, or steel grit (G-40 or coarser) is recommended. No steel shot or other non-angular blast media shall be used. The entire interior and exterior surfaces to be lined/coated shall be struck with the blast media so that all rust, loose oxides, etc., are removed from the surfaces. Only slight stains and tightly adherent annealing oxide may be left on the surfaces. The degree of the removal of these stains and tightly adherent annealing oxide shall be recommended by the coating manufacturer for specified coatings. Any area where rust reappears before lining/coating must be reblasted. Remove all burrs, slag (iron oxide), scruff, and other protuberances so that the substrate surface is flat and smooth to reduce the number of holidays and particles. Round off and open up edges of pits and holes to reduce offgassing during coating application. Round off (bevel) all sharp edges to be coated (e.g. It is necessary to grind bell shoulders and spigot edges smooth and round in profile).

4.3 Surface preparation for concrete pipes

Concrete is soft, brittle, subject to cracking, water permeable, and chemically active. Concrete pipes are more difficult to line than steel and ductile iron. Concrete pipe surfaces are anything but uniform, which can change with every pour on the same day by the same crew using the same raw materials. The surface conditions depend on the weather at time of casting, any of the mix additives or hardeners, the surface against which it is cast, and the degree of vibration used during placement. These factors create different concrete surface conditions and surface problems that impact on the application of concrete pipe coating.

The first problem is porosity. Although many methods have been used to eliminate them, concrete pipe surfaces are porous with many holes and air and water pockets. If coatings are applied over such a surface, some of the holes can be bridged or covered; however, because of the air in concrete, which expands as solvent evaporates into it, the coating blisters or the bubbles formed break, exposing the original hole.

The second problem is concrete laitance. Laitance is the very fine, light powder that floats mostly to the interior surface of concrete pipes. Because laitance has no strength and is non-adherent, any coating applied over it will have poor adhesion and be doomed to early failure.

The third problem is contamination of form releasing agents and concrete curing agents. Releasing agents containing large amounts of wax or soap are often used to help with removal of forms when the concrete has set. These releasing agents remain on the concrete surface and are difficult to remove by abrasive blasting alone. If they are not removed, the adhesion of the coating will be affected. Also, concrete curing agents present on the pipe surface will also interfere with the adhesion of the coating.

There is no formal surface preparation standard established specifically for various concrete pipes, other than the recent NACE No. 6/SSPC-SP 13 Standard which covers the general surface preparation requirement for all types of concrete[31]. The input from the coating manufacturer shall be obtained before specifying any coating for concrete pipe. In general, prior to abrasive blasting, the entire pipe area to receive the lining or coating shall be inspected for large size holes, cracks, oil, grease, rust (from joint rings of prestressed concrete cylinder pipe), excessive dust, form releasing agents, concrete curing compounds or hardeners, paints, or any deleterious substances or conditions that would interfere with the adhesion or the protective ability of the coating material. Any areas where such conditions are present shall be repaired and/or cleaned. After then, the concrete pipe surface shall be abrasive blasted to remove any loose concrete and laitance and to abrade the entire surface. Best blasting is done by light sandblasting with 60-80 mesh sand and air at 50-60 psi (3.5-4.2 kg/cm^2). Acid etching is not permitted. After abrasive blasting, all visible holes, cracks, or defective areas are to be repaired/filled by various methods and materials, such as sacking the surface with cement grout and filling with cementious or polymeric renders/resurfacers, as per recommendations by the coating manufacturer. All surfaces to be coated shall be completely dry, free of moisture, dust, grease, or any other deleterious substances at the time the coating is applied. It is also recommended that the coating application be conducted during the cooling cycle in the day.

5. PROPER APPLICATION AND INSPECTION OF A PIPE COATING SYSTEM

5.1 Quality Culture[32]

The proper application and inspection of a pipe coating system is indeed a "Quality Culture" issue. Quality Culture or Total Quality Management means that quality is addressed at every step of a pipeline project.

Quality begins with the specifying engineer. Irrespective of the type of coating job, a proper specification is the key to its success. For example, specifying an elastomeric rather than a rigid polyurethane coating direct-to-steel without a primer is normally not a good idea for steel or ductile iron pipe, because of its relatively poor adhesion, cathodic disbondment resistance, and chemical resistance. Another example is specifying a lower coating thickness (which may be adequate for smooth steel pipe) for rough ductile iron or concrete pipe, which will cause the failure of the corrosion protection. The procedure of writing an effective specification requires thorough planning for the pipeline, consideration of the needs and requirements of the coating, development of the specific key procedures for surface preparation and the coating's application, defining the requirements on applicators and support from the coating manufacturer, consideration of environmental conditions during the coating's application, description of the quality of the finished coating, and identification of the inspection/repair requirements. A specification shall be such a practical document that the owner and designer effectively communicates to a pipe manufacturer and a coating contractor what they want in a coating and what results they expect from the finished coating. The specifying engineer shall refer to applicable standards and specifications from AWWA, NACE, NAPF, etc., or refer to the coating manufacturers for specific guidelines while writing the coating specifications for a pipeline project.

The coating material approval process shall be viewed as a formality, and often is, especially when the approval being sought is for a product already specified. However, "equal" products or "similar products by listed vendors subject to engineer's approval" call for additional consideration. The contractor is often referred to alternate products based on price and availability without consideration for actual performance. A similar product by another vendor may or may not have the same performance characteristics as the products actually named or listed in the specification. Approval of an alternate product should require the same level of testing and research that went into the approval of the listed products.

In most cases, the key cause of pipeline coating failure is improper application. The quality of a pipe coating is only as good as the quality of application. It is therefore very essential to select a proper coating applicator based on: experience, reputation, reliability, conformance to coating manufacturer's specifications, modern automatic equipment, and quality control. Communicating all of the project requirements to the selected applicator and orientating the workers are keys to success in the field. The manufacturer of the coating should also be contacted for proper application recommendations for the specific pipeline project, and – even better – the application should be limited to a qualified applicator trained and approved by the coating's manufacturer. This is important, particularly because of the tendency of using more 100% solids coatings in waste and wastewater pipeline today. These types of coatings are applied with special plural component spray equipment. Training and technical support from the coating manufacturers is essential to ensuring quality application. Application quality reports shall be completed and kept. Appendix A and B are two examples of application reports for 100% solids rigid polyurethane pipe coatings.

Finally, a sound field quality control inspection program that includes quality assurance from management completes the circle of the quality pipeline coating project.

5.2 Inspection

Proper inspection is the key step in ensuring a successful coating job. The objective of inspection is to ensure that the intent of the pipe coating specification and its details are carried out. Typical areas of pipe coating inspection include: coating material inspection, to determine conformity of the coating with specifications; surface preparation inspection, to determine if the surface was properly prepared for coating; and application inspection, to determine if the coated pipe meets the specifications.

Quality control inspection is an important part of the cycle of corrosion protection by coatings and the Quality Culture. Good quality control inspection should result in the satisfaction of all parties that everyone has done the best they can to the best of their ability, both independently and collectively. A qualified coatings inspector should therefore have the proper level of knowledge on pipe coatings and application. This knowledge requirement includes: the intent of the pipe coating specification, the substrate over which the coating is to be applied, surface preparation, the pipe design and its impact on the application and effectiveness of the coating and surface preparation, various coating characteristics that can affect the application and the finished product, the application procedure and application equipment, all the contractors, and the owner[5].

The minimum instrument and reference data on hand during basic pipe coating inspection should include:

- Applicable specifications, material technical data, application procedures, product material safety data sheets (MSDS) and referenced painting industry association standards such as SSPC, NACE, AWWA, ASTM, API, etc. that apply to the work.

- Proper health and safety gear such as basic head, eye, foot and hearing protection. You should also have suitable clothing, a respirator with the proper filters and fall protection. The inspector must also meet the necessary health physics requirements such as pulmonary function test (PFT) or spirometry and pass a basic physician's physical. Other site-specific requirements such as special plant safety orientation training or blood lead testing may be required.

- Psychrometer, surface temperature thermometer and psychrometric charts to record and calculate environmental conditions (Dew point, ambient temperatures, relative humidity, etc.).

- Wet film and dry film gauges to verify the applied and cured coating thickness.

- Surface preparation standards, both written and visual. Surface profile comparator or profile replica tape.

- Adhesion testers and proper glue materials for the adhesion testing. Finding a suitable glue is one of the common problems with adhesion testing on 100% solids rigid polyurethane coatings, because of the polyurethane's superior adhesion value (as high as 6000 psi (42 MPa). Glue failure often occurs before the adhesive strength of the coatings breaks down.

- Holiday testers. For coating thickness of less than 20 mils (500 microns) on steel, the recommended holiday tester will be a wet sponge low voltage tester. Higher voltages (100 volts per mil or 4 volts per micron are often recommended) for coating thickness of higher than 20 mils (500 microns) on steel or ductile iron, and therefore a high voltage tester is needed. Holiday detecting voltage for concrete is calculated with the pipe by adding the minimum voltage required to spare bare concrete, plus a value of 25 volts per specified coating nominal mil thickness. In no case shall the calculated voltage be less than 1,000 volts total.

Appendix C shows a typical quality assurance report for 100% solids polyurethane pipe coatings.

Coating holiday inspection is the area in most cases that often results in questions by pipe coating inspections and specifying engineers. Among them the question of "how many holidays and holiday repairs per pipe should I accept in the field?" would catch the immediate attention from all parties involved including the pipe and coating manufacturer. Although sometimes costly and painful, this question is not difficult to answer if we all have an end in mind – corrosion protection by coating. First, coating holidays can cause the failure of corrosion protection by coatings, especially when the coating is not backed up with cathodic protection. So, if it is found that there is one, it should be repaired properly and retested. Secondly, the fact that too many holiday repairs per pipe have been inspected in the field is an indication of the opportunity for application quality. Thirdly, it is important to understand most coating repair materials are designed for the purpose of small area and/or holiday repairing only. Properly applied, these materials will provide excellent corrosion protection to fit their original purpose. However, the corrosion protection of a pipeline cannot and shall not depend mainly on coating repair materials. Finally, when coating holidays do occur, the number of holidays per pipeline can be eliminated or reduced to a minimum by proper coating application and handling. Therefore, the engineers, the coating and pipe manufacturers, the coating applicator, the inspector, and all the contractors shall work together to determine an agreeable maximum number of holiday repairs per pipe and to improve the application and handling quality to eliminate the source of holidays.

6. SUMMARY

Corrosion protection by coatings for water and wastewater pipelines is the implementation of a well-balanced cycle of the four equally important elements: specifying and using a proper coating system, proper surface preparation for the coating system, proper application of the coating system; and quality inspection of the coating system.

There are many coating systems available for steel, ductile iron, and concrete pipe. The proper selection of a pipe coating system shall be based on careful consideration of the following attributes: handling and safety characteristics, shop/field application and repair attributes, surface preparation requirements, physical performance requirements, case histories, and cost analysis. Physical performance requirements on a pipe coating system can be influenced by the type of soil and back fill, the use of cathodic protection, the pipe installation methods and location, and the corrosive environmental conditions that a coating is going to expose.

Steel, ductile iron, and concrete pipes have different types of surface conditions and therefore different surface preparation requirements shall be imposed. Surface preparation recommendations shall cover the needs of surface for shop coating application, inspection, repairs and field coating application.

The proper application and inspection of a pipe coating system is indeed a “Quality Culture” issue. This Quality Culture or total quality management means that quality is addressed at every step of a pipeline project. It includes a properly written specification and coating material approval process, the proper selection of an applicator, the careful coating application and handling of the finished product, and the proper quality control inspection. The implementation of this Quality Culture will go far in assuring that a high quality coating system has been installed, achieving the ultimate pipeline corrosion protection by coatings.

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32. S.W. Guan, “The Selection, Application and Inspection of 100% Solids Polyurethane Coatings for Corrosion Protection”, SSPC 2000 Conference, November 12-16, Nashville, TN., 2000

APPENDIX A APPLICATION REPORT No. 1

CHECK LIST REPORT

(This report shall be completed for each daily shift and every time a drum of lining/coating material is replaced)

Project Name: ______________________________________			Date/Shift: ___________________		
This report covers the interior lining /exterior coating application for pipe and fittings from No. ___________ to No. ____________					
Lining/coating information					
The lining/coating product name: _______________; product code: ______________; Batch # A: ________________ B: _______________					
Quantity of the lining/coating (circle approximate amount)	Container A 1/4 1/2 ¾ F		Container B 1/4 1/2 3/4 F		
Environmental Conditions					
Ambient temp.(outside): ____F Ambient temp. (inside): ____F	Humidity (outside): ______ % Humidity (inside): ______%		Dew point: ______ F Steel Temp: ______ F		
Start-Up					
A. Tighten all connections in the spray system			Yes	No	
B. Lubricate leg packings and ensure they are snug			Yes	No	
C. Agitate unopened sets of Part A and B drums for 15 minutes before setting them on the rack			Yes	No	
D. Connect and check drierite and recirculation assemblies			Yes	No	
E. Clean "Y" filters at least once every 200 gallons of materials			Yes	No	
F. Clean high pressure filters as does for the "Y" filters			Yes	No	
G. Open supply valves			Yes	No	
H. Turn drum heaters on and set to approximately 100^{o}F			Yes	No	
I. Set pump heater to 110-140^{o}F. Set hose heater to 6-8			Yes	No	
J. Recirculate the heated drum materials for at least 1.5 hours			Yes	No	
K. Perform a volume check test at the end of spray hoses			Yes	No	
L. Turn off the pump air supply and close shut-off valves at the end of spray hoses			Yes	No	
M. Turn the pump on to spray pressure. Check for any leaks			Yes	No	
N. At the spray gun, ensure the needles are properly adjusted; ensure the yoke pulls back properly; ensure the spring closes properly			Yes	No	
O. Attach the spray gun to the heated hoses. Ensure the check valves are installed properly.			Yes	No	
P. Attach the solvent flush line and ensure the needle does not leak. Ensure the solvent to be used is sufficient, fresh, and clean			Yes	No	
Q. Wrap the spray gun in a protective cloth to make clean-up easier			Yes	No	
Test Spray					
A. Spray a small test area on a piece of cardboard. Ensure there are no spray defects (fingers, pulsing, off-color, etc.)			Yes	No	
B. Check the test area over the next 15 minutes for proper curing and ensure no coating defects			Yes	No	
C. While spraying, ensure spray pressure is between 2000 and 3000 psi with a maximum differential as noted for the spray gun and spray temperature is at least 100^{o}F			Yes	No	
Signed by ___________________________________ Date: ____________________________					

Note: For daily and long-term shut down and other application procedures, please refer to detailed Application Instructions or The manufacturer's Approved Applicator Manual for 100% solids rigid polyurethane coatings

APPENDIX B APPLICATION REPORT No. 2
LINING/COATING APPLICATION

(Completing this report for every pipe and fitting is not required but encouraged. However, this report shall be completed A) for the first pipe and fittings of each shift; B) every ten pipe and fittings; C) every time a drum of material is replaced; and D) for the last pipe and fittings of each shift.)

DATE/SHIFT: ____ YOUR SIGNATURE: ____

Pipe and fittings information			**Surface preparation and temperature (^{o}F)**				**Lining/Coating Auto Specs**		**Spray information**				**Pump**	**Comments**
Pipe #	Pipe Dia.	Spec Thick	Profile	Visual Stand	Clean Steel	Pipe Temp.	Speed (ft/min)	# Pass	Pressure “A”	Pressure “B”	Temp “A”	Temp “B”	# of Cycles	

APPENDIX C QUALITY ASSURANCE REPORT

(This report shall be completed for each pipe and fitting. Adhesion test shall be conducted A) for first and last pipe of each shift; B) every time a drum of material is replaced; and C) every ten pipes.)

DATE/SHIFT: ____ YOUR SIGNATURE: ____

		Results of Quality Tests								
Pipe #	Pipe Description	Visual Exam	Dry Film Thickness (mils)			Adhesion	Holiday			Comments
			Bell	Middle	Spigot		# Found	# Repaired	# Retested	