Practical Approach to Selection, Application & Inspection of Organic and Inorganic Wastewater Linings

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Abstract

This paper provides an overview of organic and inorganic protective linings for collection systems and wastewater treatment plants from a field application perspective. The dynamic nature of corrosion, pre-job inspections, specification development, application “challenges” and inspection techniques are reviewed utilizing several case histories.

Introduction

Municipalities across the United States and in many other parts of the world are being required to increase the life expectancy of their wastewater infrastructure, specifically plants and collection systems. Increasing regulation and regionalization of water/wastewater treatment, has created an environment where corrosion rates have risen to unprecedented levels. Engineers, Owners and Contractors are being asked to provide long term protection to assets, while maximizing value. This paper will address through field histories the key components of selection, application and inspection of organic and inorganic linings for long-term wastewater protection.

Background

It is estimated that Municipalities across the United States alone will spend well over 20 Billion dollars to build, repair, and replace the existing wastewater infrastructure over the next decade. The areas of concern include all components of the wastewater treatment system with a strong emphasis on wet wells, manholes, grit chambers, digesters, aeration basins, junction boxes, trunk lines, pumping stations clarifiers and sewer interceptors.

The vast majority of these facilities were built shortly after World War II; therefore they were typically built without regard for corrosion protection. Since the primary building material of the wastewater treatment and collection infrastructures has been, and continues to be concrete, corrosion as well as abrasion are primary concerns with regards to selection of wastewater protective lining systems

To compound the challenges facing the United States, the U.S. - Environmental Protection Agency referenced suggested design life for wastewater collection systems in its “*Clean Water and Drinking Infrastructure Gap Analysis”* report. This paper included the following design life recommendations:

- 80-100 Yrs --- Collection Systems
- 50 Yrs --- Treatment Plants - Concrete Structures
- 50 Yrs --- Pumping Stations - Concrete Structures
- 90-100 Yrs --- Interceptors

Whether or not all protective systems meet this requirement is still debatable, but the desire of the Government is to provide long-term solutions.

Mechanism of Corrosion

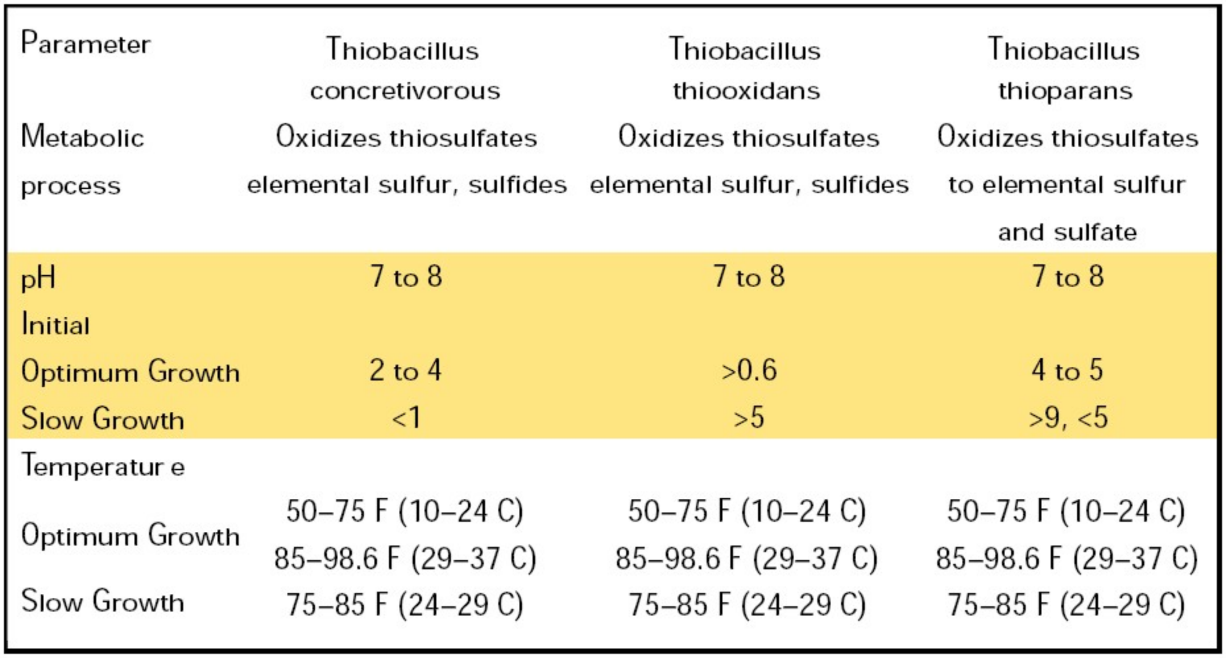
Corrosion of concrete, steel and other materials of construction has long been a problem in the municipal wastewater collection and treatment industry. Some geographical areas experience significantly greater corrosion problems than others, however, no areas of the United States are exempt from the microbiologically induced corrosion (MIC) process. The responsible authorities were slow to recognize the problem and researchers were incorrect, in their early assessments of the primary cause of wastewater corrosion. Consequently, proper remedial and preventive actions were slow to be adopted. The wastewater industry has long relied on the many industry standards that have specified the use of so-called sulfate-resistant concretes, based upon ASTM Type II Portland cement. This reliance was based upon the mistaken belief that Type II cement resists acid corrosion better than Type I cement, the type used in the construction of most of the infrastructure.

In addition, the wastewater industry had operated upon the mistaken assumption that Hydrogen Sulfide (H_2S) was the primary causative agent in the corrosion process. It is now known that biogenically generated H_2S plays the initiating role in the actual corrosion mechanism; but the overall contribution of H_2S to corrosion is moderate at best. H_2S does; however, play an extremely critical role in the facilitation of MIC.

It has been known, since before the turn of the 20th century, that concrete exposed to H_2S producing sewage does experience corrosion. It has also been known, since 1926, that sulfuric acid (H_2SO_4) was the corroding medium, not H_2S. What the researchers and other authorities did not understand was the operating mechanism used to convert H_2S to H_2SO_4. The wastewater industry now knows that the operative mechanism is microbial. Certain microbes respire H_2S and use it to chemically reduce organic sulfates found in sewage. By this method, these microbes produce the energy needed to survive. The chemical reduction of sulfates oxidizes H_2S to H_2SO_4. The microbes involved are referred to as Sulfate Reducing Bacteria (SRB) and there are anaerobic and aerobic species that are usually involved in the process. Examples of aerobic microbes are the strains of Thiobacillus bacteria and the anaerobic strain is usually Desulfovibrio desulfuricans (D. desulfuricans). D. desulfuricans uses the iron in embedded reinforcement steel to catalyze the sulfate reduction.

New concrete will range from a pH of 12 to 13. Carbon dioxide (CO_2) and H_2S condense with water vapor to form weak acidic conditions. These condensates then react to form thionates and carbonates and to lower the pH below 11. From this point, there is a progressive growth of various microorganisms, including Thiobacilli bacteria (see Table 1). Many of these microbes secrete acid waste products, including organic acids and H_2SO_4 acid. As the pH of the concrete is steadily lowered, the conditions become more favorable to the destructive Thiobacillus concretivorous bacteria, which will survive from $pH > 7$ to $pH < 1$, and the Thiobacillus thiooxidans bacteria, which will survive to a $pH < 0.6$.

Table 1: Environmental Conditions Promoting Thiobacillus Growth



Parameter	Thiobacillus concretivorous	Thiobacillus thiooxidans	Thiobacillus thioparans
Metabolic process	Oxidizes thiosulfates elemental sulfur, sulfides	Oxidizes thiosulfates elemental sulfur, sulfides	Oxidizes thiosulfates to elemental sulfur and sulfate
pH Initial	7 to 8	7 to 8	7 to 8
Optimum Growth	2 to 4	>0.6	4 to 5
Slow Growth	<1	>5	>9, <5
Temperatur e			
Optimum Growth	50–75 F (10–24 C) 85–98.6 F (29–37 C)	50–75 F (10–24 C) 85–98.6 F (29–37 C)	50–75 F (10–24 C) 85–98.6 F (29–37 C)
Slow Growth	75–85 F (24–29 C)	75–85 F (24–29 C)	75–85 F (24–29 C)

It is imperative to understand the meaning of pH. The pH scale is a logarithmic measurement of the H+ ion. Historically, the pH scale has been utilized to measure the strength of an acid, and it can be done that way when measuring a known acid or combination. For example the strength of sulfuric acid at pH of 2 is 10 times more concentrated than the same sulfuric acid at pH of 3. However it cannot be utilized to compare the strength of acid A to acid B. Citric acid at pH of 3 is called orange juice and is consumed daily whereas sulfuric acid at a pH of 3 will destroy the esophagus in minutes. It is also instructing to note that a pH of 1 in a sulfuric acid environment equates to concentration of 0.01% sulfuric acid in solution.

It is well established that materials used in the sewage infrastructure corrode in acidic media and these structures unprotected are unsuitable for these exposures. There exist some common misconceptions regarding the mechanism for concrete corrosion. Not surprisingly, this mechanism does not significantly differ from those for metallic corrosion. The degree of access to the concrete matrix, moisture, temperature, pressure, velocity of corrodent streams, time, media composition and concentration are all controlling factors. One of the common misconceptions encountered is that a high relative humidity is required for concrete to corrode. All that really is required is for the corrodent to be deposited as a liquid directly onto the concrete or for sufficient moisture to be present. This condition will allow for condensation of those species that are below their dew point. This level may be reached at as little as 0.1% atmospheric moisture. Once condensation occurs, there exists enough free moisture in the concrete to allow reactions to proceed autogenically. About 80% of the water mixed with the typical Portland cement based concretes actually enters into the hydration reactions. The rest is “water of convenience,” which allows the mixture to be placed in its final location. This “water of convenience” remains trapped within the concrete matrix, available to dissolve, ionize and react. It is true that microbiologically influenced corrosion (MIC) in wastewater collection and treatment systems tends to be more aggressive in structures with higher atmospheric moisture. This fact, however, is due more to the formation of an environment favorable to rapid growth of bacteria, which includes appropriate moisture levels.

The acidic secretions from the Thiobacilli bacteria are liquids and are secreted directly onto the concrete. These liquids are subsequently held in place by a blanket of the other acid secreting microbes and other constituents of the biofilm, which also influences their rate of oxygen diffusion to the substrate. The free lime (CaO) in Portland Cement will react quite readily with any concentration of sulfuric acid at all temperatures above the freezing point of the acid present.

Another misconception in the industry is that the primary source of corrosion is H_2S attack on concrete. While it is true that strong concentrations of H_2S will eventually corrode the Portland cement matrix, the reaction is neither vigorous nor rapid and it is highly dependent on H_2S levels, water/moisture availability temperature and time. In terms of competing reactions, the Portland - H_2SO_4 - H_2O, reaction will control vis a vis the Portland - H_2S - H_2O reaction, to the point that the latter will be unimportant, except for its major role in the initial acidification of the substrate. Of course, H_2S concentration also directly influences the rate of growth of the Thiobacillus bacteria, as the microbes use it as a respirant, and is thus critical to the overall process.

A widely cited study by C. D. Parker on the MIC process dates back to 1951. For one strain of Thiobacillus bacteria – Concretivorous - Parker reports the effect of temperature on relative rates of H_2SO_4 formation. As expected, the metabolic process is accelerated as temperatures rise, showing a peak at ≈30°C (86°F). The acid concentrations and volumes are sufficient to destroy a large quantity of concrete, since one part of H_2SO_4 by weight will react with and destroy 2 1/2 parts of Portland Cement, based on stoichiometric ratios. Estimates of the biogenic H_2SO_4 concentration ranges as high as 40% H_2SO_4, by weight. Most municipalities are looking to design systems that will withstand worse case exposures.

Application of loads such as bending and tensile stresses accelerates the corrosion rate by weakening and rupturing already brittle bonds. As these bonds deteriorate, corrosion of the reinforcing steel further aggravates the corrosion problem by destroying the reinforcement and by inducing additional stresses on the concrete due to the internal formation of iron sulfates on embedded steel. These iron sulfates then expand to a volume up to 12 times that of the original steel and the swelling thus produced contributes to cracking and spalling of the concrete.

Linings

Inorganic Linings

Inorganic linings have been used in wastewater environments over the past 50 years, with significant success, particularly in areas where inflow and infiltration are primary cause of concern. Fiber reinforcement is often incorporated to minimize shrinkage cracks and provide increased physical properties.

Sulfate-Resistant Cement

- Typically used in new construction or as a resurfacer for rehabilitation projects
- Typically cast in place (new construction) or applied by trowel or spray (rehabilitation)

- Thickness 1/4 “ → 10” +

Sulfate-resistant cement was utilized extensively in the mid-late 20th century with little success. Although the ASTM C-150 Type II cement is resistant to some degree to sulfates, it is not resistant to Sulfuric Acid (H2SO4). Type I and II Portland cement are both strongly alkaline (ph>7) and susceptible to chemical attack from dilute acid concentrations (less than 2%). As shown below the weight gain and loss of physical strength of Portland cement structures, indicate the need for protective lining if long life expectancy is desired.

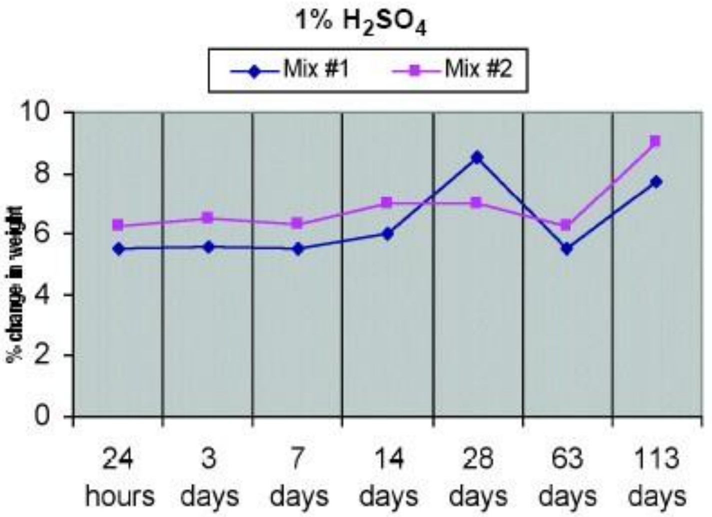


Figure 1: Effect of Weak H_2SO_4 on Weight of Types I and II Portland Cement over Time

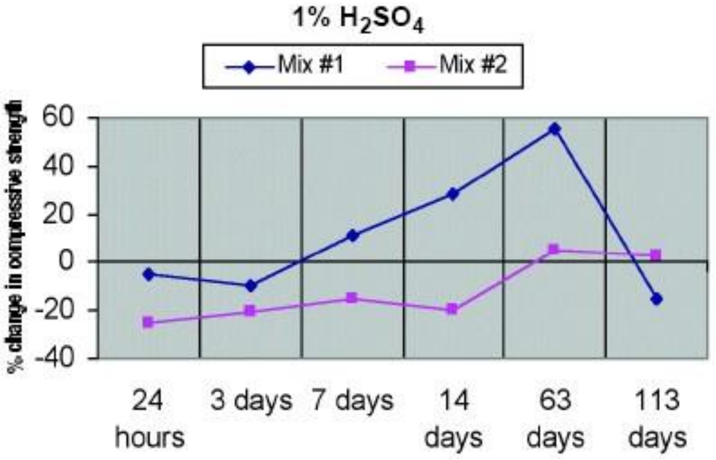


Figure 2: Effect of Weak H_2SO_4 on Compressive Strength of Types I and II Portland Cement over Time

<u>Potassium Silicates</u>

- Historically used as a monolithic barrier in conjunction with an “impervious” membrane
- Applied by gunite method or cast in place

Potassium silicates lining systems provide excellent corrosion protection to highly acidic environments (ph<7), and exposure to acid actually increases its physical properties. Unfortunately these systems are susceptible to chemical attack when exposed to environments with a pH above neutral (pH>7).

Calcium Aluminates

- Typically utilized to address inflow and infiltration and mild corrosive environments
- Applied via gunite, shotcrete, rotary spray, or trowel

Calcium Aluminate Cement linings are typically used in environments with inflow and infiltration concerns and which require a moderate level of resistance to microbiologically induced corrosion. These systems provide rapid return to service capabilities and have been used in moderately aggressive environments.

Organic Linings

Organic linings can be broken down into two dominant categories: liquid-applied polymers and sheet linings (PVC or HDPE).

Liquid-Applied Polymers – are further categorized by polymer type, including the following:

Epoxy Liners

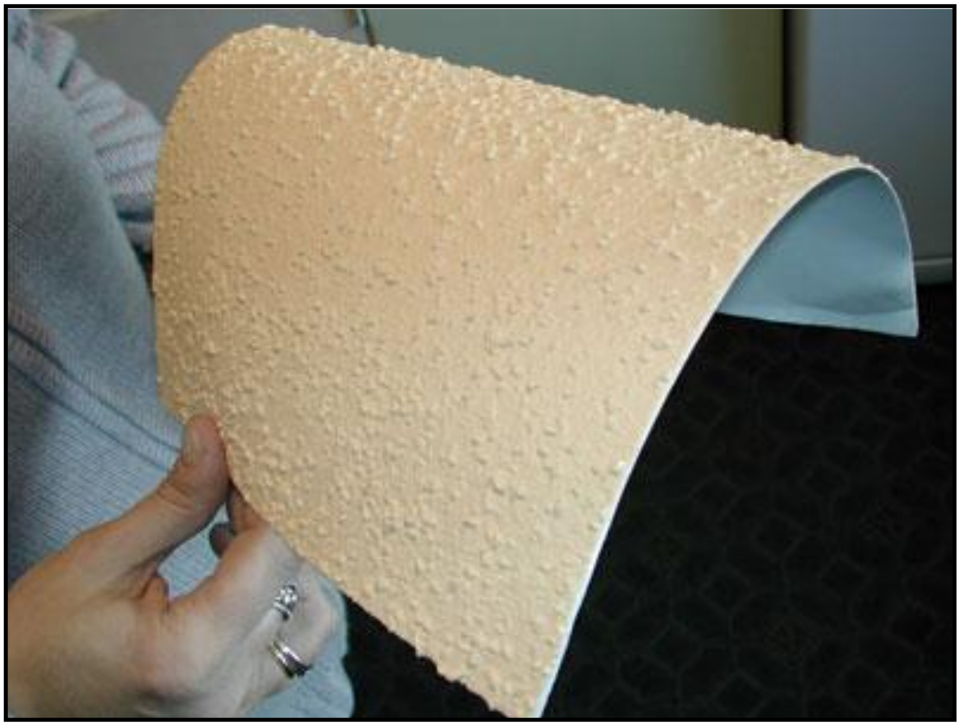
- Utilized in new construction as well as rehabilitation. Often in conjunction with organic or inorganic restoration materials
- Applied via spray or trowel methods

Epoxy liners have been used in wastewater environments for more than 40 years and have developed a solid reputation. Over the past 20 years thick film 100% solids hybrid epoxy liners have become widely accepted. They combine excellent resistance to biogenic corrosion with physical properties superior to that of concrete. While tolerant of damp surfaces, these materials do not offer the extended elongation capabilities of other polymer systems. Particularly attention needs to be made to the composition of the epoxy, as some components have been known to be a food source to biological organisms.

Urethanes/Urea’s

- Typically utilized in new construction applications.
- Applied via high pressure spray equipment

When compared to their Epoxy counterparts, Polyurethane and Polyurea technologies are newer to the wastewater industry. They offer excellent flexibility, quick cure capabilities, moderate chemical resistance and a single coat application. Polyurethane (reaction of a urethane and isocyanate) derivates are moisture sensitive, so their application in damp environments can create adhesion concerns, so the use of primers becomes paramount. The polyurea systems (reaction of a urethane and amine) provide moisture tolerance but have reduced chemical resistance.



Sheet Goods

- Shop manufactured materials
- Better suited for new construction via hand lay up and seam welding

Plastic Sheet Goods consisting of Poly-Vinyl Chloride (PVC) and High Density Polyethylene (HDPE) have been used in water and wastewater pipe with very good success. These materials offer excellent chemical resistance and low permeation and are ideal for applications that can be completed in a shop environment such as reinforced concrete pipe manufacturer. It is more difficult to apply these materials in-situ as they need to be formed in place and the seams between the sheets must be welded or taped.

CASE HISTORY – MANHOLE REHABILITATION IN THE SOUTHWESTERN U.S.

The Southwestern U.S. provides unique challenges to corrosion control within municipal wastewater treatment and collection systems. Higher year-round temperatures exacerbate the rate of microbial corrosion within these environments. While some owners take preventive measures by lining concrete structures prior to placing in service, others take a wait and see approach, preferring to save on the initial cost of a given project.

A particular Southwestern city opted for the wait and see approach on manholes they believed would see exposure to minimal amounts of hydrogen-sulfide gas and the resulting sulfuric acid. The decision to install unprotected, precast manholes was based on a smooth, non-turbulent flow through the line. Within two-years an inspection revealed that corrosion was occurring within these relatively new structures and that corrective measures were required.

For this rehabilitation project, the following corrective specification including application and inspection was followed:

1. Surface Preparation consisted of high-pressure (5,000 psi) water blasting to remove all weak, acid-attacked concrete. (Figure 1 – shows the condition of the prepared substrate)
2. pH testing of the concrete surface was conducted to ensure that all acid residue was removed.
3. A "pull-test" was performed to make certain the prepared concrete had sufficient tensile strength. A minimum strength of 250 psi was required.
4. A fast-setting waterplug was used to stop a small amount of infiltration, which existed.
5. A fast-setting, cement-based resurfacer was applied to a thickness of ¼" to the interior of all prepared manholes. This step provides a uniform surface for application of the protective lining material. A consistent thickness of the protective liner can then be tested for pinholes. (Figure 2 illustrates the resurfaced structure)
6. After an overnight cure, a 100% solids, moisture tolerant epoxy mortar was trowel-applied over the resurfacer in a single coat to a thickness of 125 mils.
7. After a 24-hour cure the epoxy lining was tested for adhesion, using the same method employed for determining tensile strength of the substrate.
8. The epoxy lining was then tested for pinholes or "holidays." The detected pinholes were easily repaired, providing a monolithic, pinhole-free lining. (Figure 3 illustrates a completed structure)

Why were conditions in these manholes much worse than anticipated? Although turbulent flow, or the lack thereof, is a good indicator of the corrosiveness within a structure, there are numerous other contributing factors. One being the composition of the sewage. As it turned out, discharge from a fruit juice manufacturing facility upstream of the manholes played a role in lowering the pH on the surface of the manholes. This accelerated the formation of acid-producing bacteria. This, in combination with a long retention time and warmer climate created an aggressive environment, with corrosion rates of ¼" per year.


Figure 1.


Figure 2.


Figure 3.

Key Points of this Project:

1. A well-written specification spelled out the required installation steps including the important, in-field quality control measures to be followed.
2. A contractor trained and certified by the manufacturer was required for the application.
3. The selected products were designed specifically for application within wastewater environments.
4. All products, including the water plug, cement-based resurfacer and the epoxy-based protective lining material were provided by a single manufacturer, which ensured compatibility and accountability.
5. Inspection of the finished product by all parties including holiday detection in accordance with the National Association Of Corrosion Engineers recommended practice.

CASE HISTORY – MAIN TRUNK SEWER REHAB

When a New Jersey municipality decided to rehabilitate an 84-inch main trunk sewer, built in the 1950's, there were many considerations. This 2,200-foot section, which is a critical link in the county's trunk sewer system, had experienced extensive concrete deterioration. Additionally, water inflow and infiltration was widespread.

The municipality, with the assistance of an engineering firm investigated options including complete replacement, pipe-jacking and slip lining. Given the depth of the pipe, limited access and other logistical considerations, the decision was made to restore the line using a gunite-applied restoration material and a spray-applied epoxy lining. This method was determined to be the most economical and also the least disruptive to the immediate area.

As the project commenced, it was quickly learned that degradation of the line was much more extensive than originally thought. Ultra-high pressure water blasting was removing up to 4 inches of weak, chemically attacked concrete. In addition, much of the steel reinforcement was damaged beyond repair. The following steps were required for completion of this project:

1. After surface preparation, an extensive amount of pressure grouting with hydrophilic polyurethane was performed to eliminate inflow and infiltration.
2. New reinforcement was installed for the application of a repair material.

A proprietary high strength, rapid setting Portland cement based resurfacing material that could be top coated with the a compatible lining system within hours, was selected to rehabilitate the substrate. A hybrid polymer system based upon 100% solids technology was designed and tested for wastewater environments to prevent the type of deterioration found in the Middlesex pipeline.

County that the restoration requirements would be significantly greater than originally planned. A contingency such as this had been allowed for and the extra work was approved.

The contractor had initially planned to apply the restoration mortar via a small concrete pump, but with the drastic increase in the scope of work this would not have been practical or economical. Fortunately, the contractor’s experience and the versatility of the manufacturer’s products provided a solution. The substrate resurfacer is also manufactured in a gunite form, designed specifically for rapid application of large amounts of material.

The gunite application was approved and a subcontractor specializing in this type of application was selected. This subcontractor installed anchors and reinforcement where required and gunited over 300,000 lbs. of substrate resurfacer in thickness over 4 inches. This phase was completed in approximately 3 weeks and effectively restored the integrity of the pipeline and provided a uniform substrate for the application of the epoxy corrosion resistant barrier.

As each area of the gunite application of the substrate resurfacer was completed it was given a broom finish. This provided a mechanical profile to bond the polymer lining, which was spray applied by the contractor after all the underlayment work was completed.

Most of the damage to the pipe was in the “crown” or top portion of the pipe. This is typical in municipal wastewater, where the acid producing bacteria thrive in the vapor zone above the water level. Most often, little or no damage takes places below the water level. Other forms of rehabilitation, such as pipe jacking or slip lining require that the entire circumference of the pipe be treated. This increases the rehabilitation cost significantly. Polymer products can be installed only where the damage has occurred or where there is the potential for corrosion and, as evidenced by this project, the product versatility allows for adaptation to variable jobsite conditions. This allowed the contractor to restore the pipe economically and then provide the corrosion resistant barrier. This will prevent the recurrence of the damage associated with micro-biologically induced corrosion.

Using this method of restoration and protection enabled the contractor to complete the job in a reasonable amount of time without major disruption to the locale and provide long-term corrosion protection. According to the engineer, using this method versus pipe jacking or slip lining saved the county 20%-30% in costs.

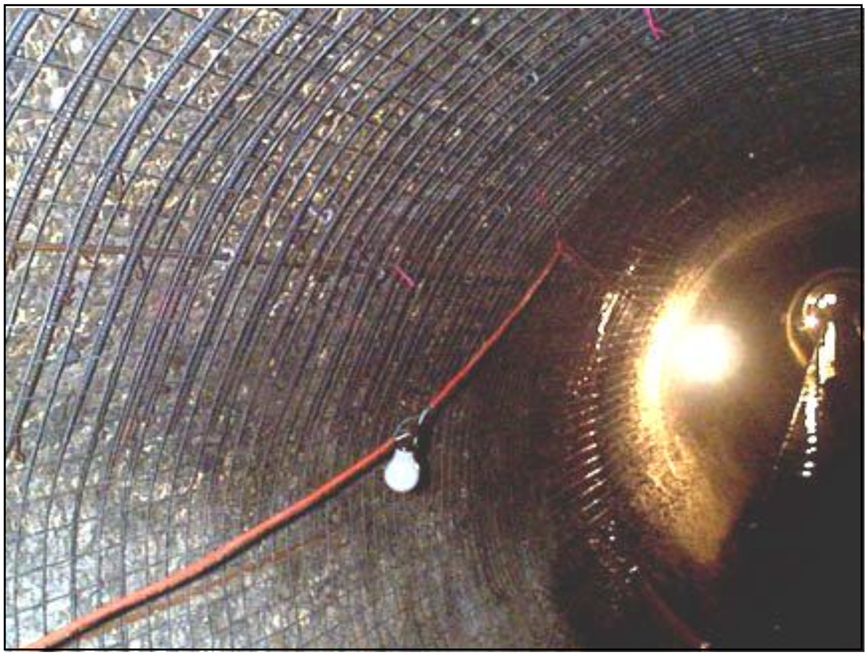
- Concrete restoration, as much as 4-1/2” thick, accomplished with a gunite version of rapid setting, high strength substrate resurfacer, avoiding delays and minimizing cost.

This 100% solids hybrid polymer lining system will prevent any further corrosion in this aggressive environment.

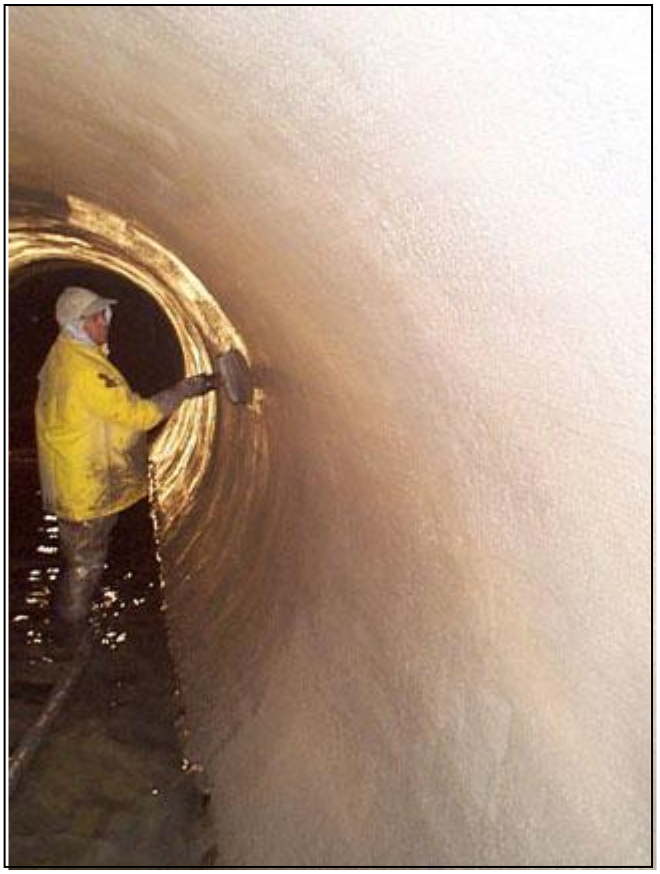
1 - Pipeline showing dramatic evidence of corrosion and water inflow.

#2 – Exposed aggregate and corroded rebar illustrate the critical need for restoration.

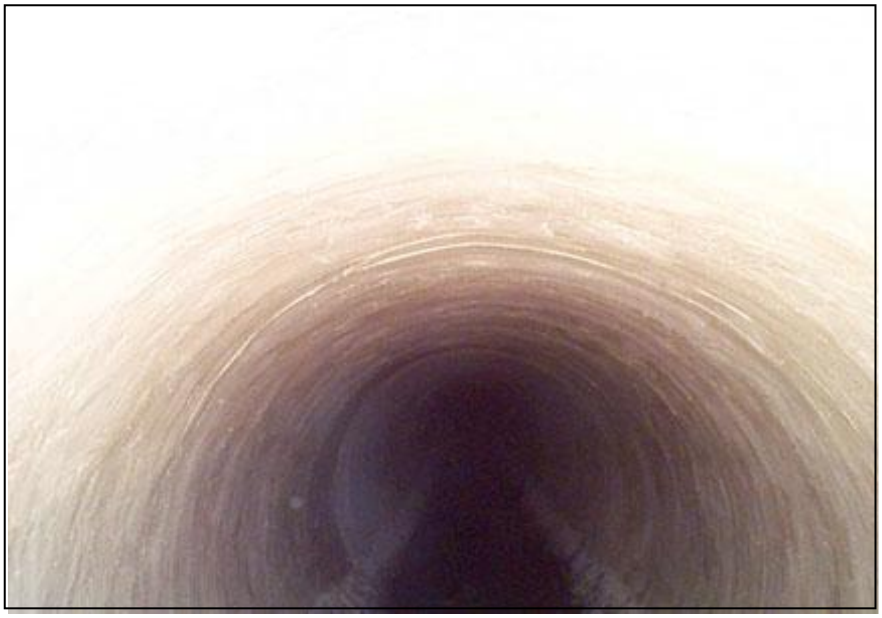
#3 – Newly installed rebar awaits gunite-applied concrete restoration.



#4 – Finishing touches applied to the underlayment prior to application of protective epoxy lining.



5 - Completed pipeline with concrete restoration and corrosion resistant hybrid polymer lining.



CONCLUSION

Today's wastewater engineers are facing unprecedented levels of corrosion in their collection and plant systems, while being asked to provide life expectancy's of these structures which span generations. The challenges to select, apply and inspect protective lining systems has never been greater. Although industry standards are beginning to provide tools to measure the effectiveness of various technological solutions, the key to providing long term solutions is to look at today's successful technologies..

Critical factors to the long-term performances of any lining system in aggressive wastewater environments include abrasion, impact resistance, chemical resistance and permeability. Obviously the selected materials can not provide a growth platform for microbes.

The manholes and sewer interceptors cited above provide a glimpse into several successful technologies which when properly selected, applied, and inspected provide long-term solutions for the public at large.

ACKNOWLEDGEMENTS

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