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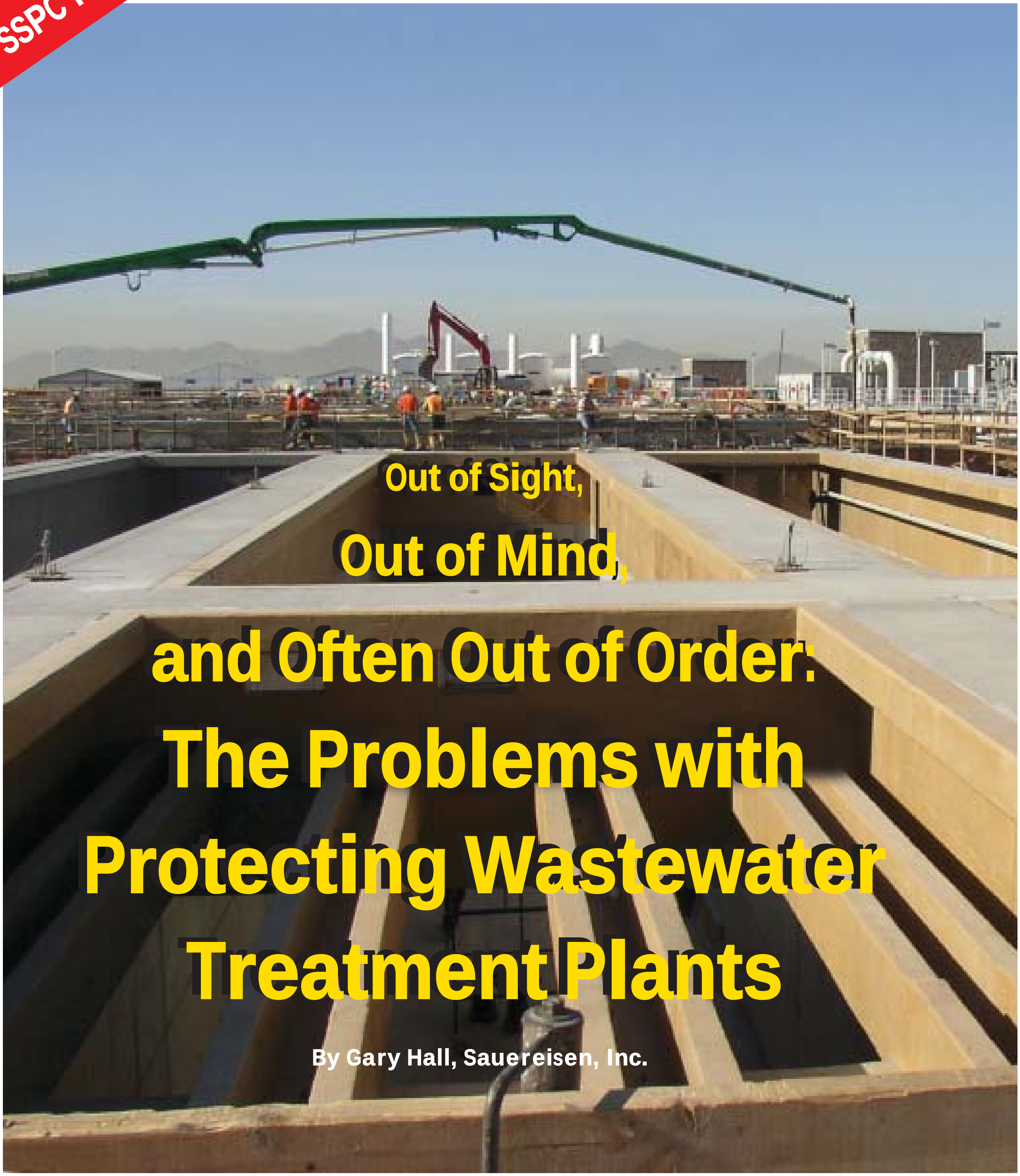
JPCL
JOURNAL OF PROTECTIVE COATINGS & LININGS
Reprinted from October 2004



Out of Sight, Out of Mind, and Often Out of Order: The Problems with Protecting Wastewater Treatment Plants

By Gary Hall, Sauereisen, Inc.

Out of Sight, Out of Mind, and Often Out of Order:

The Problems with Protecting Wastewater Treatment Plants

(above) Large wastewater treatment in Arizona with (tan) epoxy liner applied

By Gary Hall, Sauereisen, Inc.

(above) Gravity thickener tank (rehab.) lined with 20 mils (½ mm) of epoxy
(left) Underground clarifier lined with ¼-inch (6-mm) epoxy mortar
Photos courtesy of the author

Collections. Drains. Sewer Lines. By whatever name they are called, they and their associated treatment plants present unique protection and maintenance challenges. Imagine being asked to put a coating on concrete that is saturated with water, covered with grease and a nasty biofilm, heavily attacked by sulfuric acid, and contaminated with bacteria. Imagine, too, that surface preparation techniques at best remove degradated concrete and surface contaminants but have no effect on the level of moisture in the substrate or the degree of subsurface microbial colonization. Suppose your coating has to cure at cool temperatures in an environment that is at more than 90% RH and filled with hydrogen sulfide. That is enough to make even hardened coating applicators nervous and the best coating formulator sweat. Yet those are precisely the conditions found in wastewater collection and treatment systems.

A system that is out of sight and out of mind is often out of order. To say there are "coating issues" in wastewater treatment systems is a classic understatement. Contributing to those issues are two underlying factors—a basic lack of understanding of the cause of deterioration on the part of the industry and its specification writers, and an all too common material specification for the concrete that demonstrates the combined effects of insufficient information and a resistance to change. This article highlights these issues, outlines the corrosion mechanisms involved, and discusses substrate specifications and coating selection, including properties and chemistry.

Germs and Other Nasties

As one would suppose, the environment of a sewage collection system is one of the least sterile imaginable. Perversely, it is the very lack of sterility that at once makes the system work as efficiently as it does and that is the cause of myriad problems. The process begins with decomposition of solid wastes in the sewage. To travel from any particular home or building on the system to the wastewater treatment plant (WWTP) requires several days, on average. During this time, anaerobic bacteria, which function in an airless environment, are present in the solid wastes, along with water-aided dissolution and agitation due to flowing and tumbling through the pipeline. These factors cause the waste solids to break up. The microbes release hydrogen sulfide (H_2S) as they form sulfate-containing organic compounds:

$$\text{Waste solids + microbes} \xrightarrow[\text{agitation}]{\text{water}} H_2S\text{ + polythionates + sulfates}$$

The bacterial digestion of the solids forms polythionates and other sulfates, some of which are deposited on the concrete.

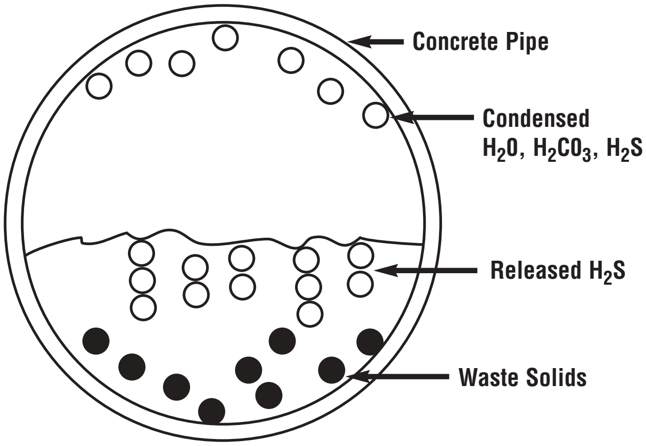
In the air spaces above the sewage, water vapor (H_2O) and carbon dioxide (CO_2) are ubiquitous. Collecting on the concrete, the condensed H_2O dissolves both the CO_2 and H_2S, resulting in a solution of H_2S and carbonic acid (H_2CO_3).

Metals are also used in various ways throughout wastewater treatment systems. Concrete usually contains metallic reinforcement (rebar). Ladders, sluice gates, and other metallic substrates offer opportunities for corrosion. Microbiologically influenced corrosion (MIC) on metals is no different than any other electrochemical attack. The microorganisms involved can cause the same sort of corrosion problems seen in other environments. They may accelerate corrosion from other sources, such as industrial discharges. Corrosion phenomena such as pitting, gaseous concentration cells, crevice corrosion, exfoliation, and selective de-alloying are all found with MIC.

Most instances of MIC result from highly complex interactions between groups of microorganisms, not all of which are bacteria. Molds, mildew, fungi and yeasts, and many species of bacteria can contribute to corrosion. Due to this multiple organism environment, simply testing a material's resistance to H_2SO_4 or one microbe does not replicate field conditions. The only meaningful test is in fact multiple field exposures in a variety of locales and systems.

The presence of multiple species of microorganisms may complicate surface preparation. Some microorganisms are anaerobic and may infiltrate concrete, which typically has upwards of 10% total porosity as measured by ASTM C-20, Test Methods for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick and Shapes by Boiling Water.

Different microbial species will introduce other chemical species. For example, halophillic bacteria may be associated with chlorides or other halogens. Due to the highly complex interactions between groups of microorganisms, the chemistry at the substrate/ biofilm interface is far different than if the biofilm was not present. The differences may include pH, dissolved oxygen, organic and inorganic compounds, and entrapped/ dissolved gases such as H_2S.



Different microbial species will introduce other chemical species

New concrete after abrasive blasting to remove laitance and expose bugholes

Same surface after filling voids/bugholes with epoxy filler compound

Virgin concrete, dependent upon the mix design and degree of carbonation, has a pH of 12.5 to 13.5. The alkaline concrete begins to react with the carbonic acid/ H_2S condensate and the surface pH begins to drop. Unhindered, these reactions will eventually lower the pH to about 8.

Also ubiquitous in the air space are the Thiobacillus bacteria. As the plural form indicates, there are more than one type, or strain, of Thiobacillus, including one called Th. Concretivorous, or "concrete devouring" Thiobacillus. These bacteria respire H_2S and consume polythionates. They metabolically reduce these sulfates and produce sulfuric acid (H_2SO_4), which has a concentration that is strain dependent. The concentration of H_2SO_4 ranges from 1.6% to 60.40%. Our friend Th. Concretivorous secretes >40wt% H_2SO_4. This sulfate-reducing bacteria (SRB) is aerobic, functioning in a gaseous environment, usually one that includes oxygen. The SRB lodge on the concrete above the sewage, where they secrete their H_2SO_4 waste. Of course, the H_2SO_4 greatly accelerates the corrosion process, the rate of which is ultimately dependent upon the strain of bacteria present and how successful it has been at proliferation. This phenomenon is also MIC.

An Underlying Problem

After WWII, specification writers began to call for the use of Type II portland cement in concrete sewer pipes and appurtenances. Type II portland, a so-called "sulfate-resistant" cement, was chosen with the mistaken belief that it would withstand acids better than Type I, the "standard" cement used in construction. ASTM C-150, Specification for Portland Cement, does promote the resistance of Type II to neutral and alkaline sulfates common to ground water.

However, all portland cement is strongly alkaline and will readily react with even the weakest H_2SO_4. A study published in 1993 by the author[1] and G. Maloney illustrates that Type II deteriorates to a greater degree than Type I after 6 months' exposure to a H_2SO_4 solution that was only 5wt%. After one year the Type II had suffered significantly more strength and mass loss than Type I, which was itself essentially destroyed. Figures 1 and 2 illustrate the effect of an even weaker 1% H_2SO_4 solution on Types I & II portland. Figure 3 is a control mix of Type II unexposed. Figures 4 and 5 demonstrate the effect on calcium aluminate cements. As can be seen in Fig. 5, the calcium aluminate cements are rapidly attacked at 40% H_2SO_4, the acid concentration secreted by Th. Concretivorous.

Much of the municipal collection infrastructure in the United States and elsewhere has suffered significant corrosion loss because of the initial ignorance of the properties of portland cement, in general, and of Type II, in particular, and a misunderstanding of the overall destructive mechanism including the microbial role. Many large sewer lines have collapsed as a result. Inertia has kept the process running. Inertia on the part of industry "experts" has kept them from correcting past errors in design specifications and material choices. Inertia on the part of system owners, because the system is "out of sight," has created chronic funding shortfalls and an unwarranted and ultimately unwise dependence upon contractors for material selection rather than qualified engineers. The municipalities and their design engineers should have the ultimate objective of obtaining the *lowest total cost/unit area* over the structure's expected life. In reality, they often jointly conspire with the contractor to obtain the *lowest installed cost/unit area*. The former is good engineering practice and money management. The latter ignores known facts and is a gamble that too often proves costly.

To Coat or Not To Coat?

The environment and the elements of the corrosion process exist throughout the collection system. Moreover, they exist from one system to another in areas as different as Alaska, Puerto Rico, and Arizona. Regardless of locale, the same microbes are present; H_2S is given off; polythionates are formed; and H_2O is present. Yet some systems have little or no corrosion while others lose six or more inches of concrete in less than four years. In some systems, one area exhibits severe corrosion while another shows none. Given this, how do we decide whether to coat or not to coat? With what do we coat? How do we specify the coating? What properties are needed? How do we rehabilitate substrates prior to protecting them?

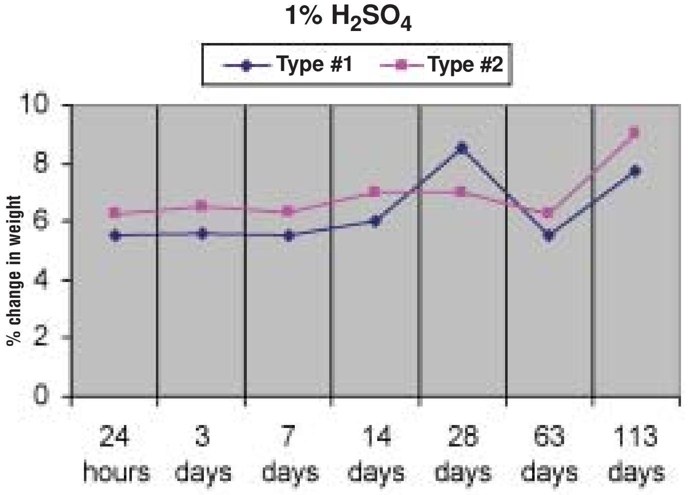


Figure 1: Effect of Weak H_2SO_4 on Weight of Types I and II Portland Cement over Time

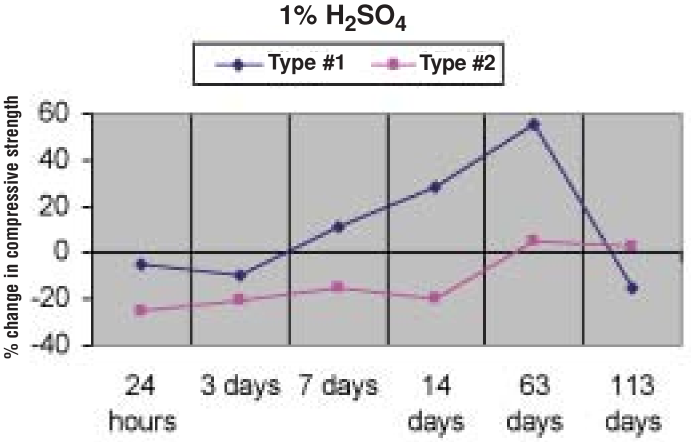


Figure 2: Effect of Weak H_2SO_4 on Compressive Strength of Types I and II Portland Cement over Time

History is a valuable tool. History can provide clues that enable us to evaluate data, much of it anecdotal in our case. The history of a given collection system will obviously indicate where the effects of corrosion have been observed. That is one prong of the multi-pronged problem. Until relatively recently, most pipeline interiors were rarely if ever seen once placed in the ground. We only knew about problems when they produced observable effects like collapse and leakage. Today, the means exist to visually inspect pipeline interiors in place. This allows for the collection of data and decision making based upon this data.

Some industrial companies and a few technical organizations have taken the lead in determining the cause of corro-

Bottom side view of 12-inch x 12-inch x 6-inch (30-cm x 30-cm x 15-cm)reinforced concrete steel beam in wet well. Six years' service in Louisiana wastewater treatment collection system. Concrete loss is greater than 4 in. (10 cm)

sion and developing data or means to combat the corrosion or prevent it. Organizations such as NACE International, Water Environment Federation (WEF), and the International Concrete Repair Institute (ICRI) have provided a public forum to help elucidate the problems, causes, effective remediation, and quality control. Others such as SSPC: The Society for Protective Coatings have helped train the industry and its consultants and contractors to correctly specify and apply coatings for corrosion protection.

We now recognize and understand the conditions that lead to MIC and the mechanisms involved. Where do we apply protective coatings? As stated above, within one collection system, there can be some areas exhibiting severe corrosion and others exhibiting very little or even none. Examination of hundreds of systems, in person or by video, has given us enough data to make some generalizations about the conditions and locations likely to corrode. One very important caveat underlying these generalizations is that fixing the problem in one area may exacerbate the situation downstream. The bacteria may prefer one area to another due to a localized variable such as a higher H_2S concentration. Eliminating their growth support platform, for example, by applying a coating, may cause them to move on to a less desirable area. Being highly adaptable, they lodge, proliferate, and start the MIC process in a new area. Table 1 lists some of the Th. bacteria and their ideal growth conditions; Table 2 lists some areas especially prone to MIC.

As mentioned above, some parts of the wastewater treatment system will not be subject to corrosion. Indeed, sometimes an entire collection and treatment system may have only limited corrosion. Why does one system in Vermont show no corrosion, yet a system in Florida shows severe corrosion? We now know that systems with forced-mains will undergo much less MIC compared to gravity-flow systems. When sewage is pumped through forced-main systems, the pipe is full and the pressure of the flowing water helps to dilute any acid present and to remove biofilms. The more often

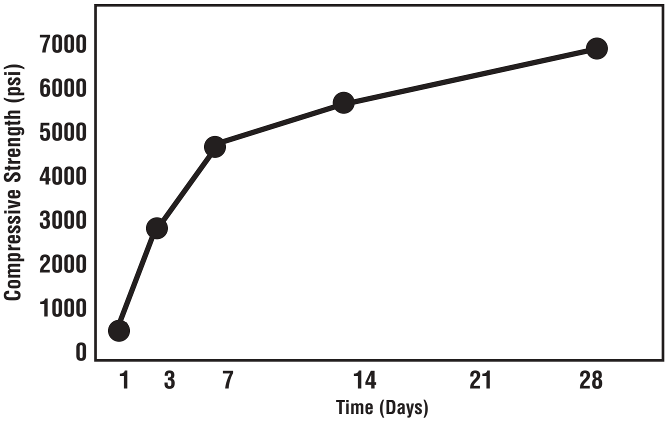


Fig. 3: Change in Strength vs Time

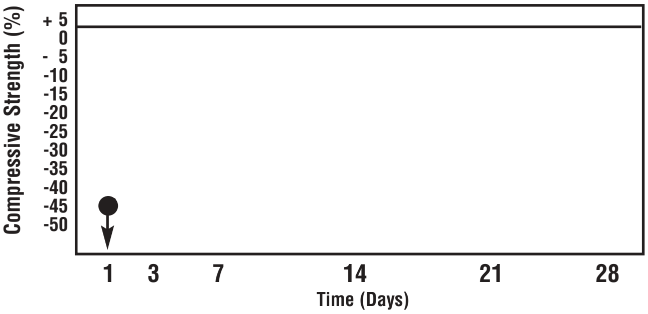


Fig. 4: Change in Strength of Calcium Aluminate Cement vs Time for 37.5% HCl Immersion

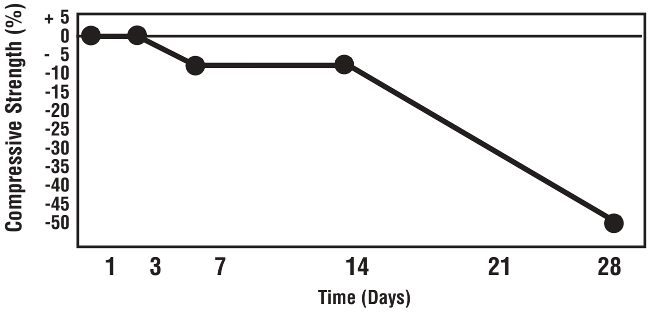


Fig. 5: Change in Strength of Calcium Aluminate Cement vs Time for 40% H_2SO_4 Immersion

Concrete comparator panels from ICRI being used to determine adequacy of surface preparation

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	7 to 8	7 to 8	7 to 8
Initial			
Optimum Growth	2 to 4	>0.6	4 to 5
Slow Growth	<1	>5	>9, <5
Temperature			
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)

Table 2: Areas in Wastewater Collection and Treatment Systems Prone to Corrosion

- Manholes
- Lift Stations/Pumping Stations
- Grit Chambers
- Junction Boxes
- Drop Manholes
- Digesters
- Clarifiers
- Sludge Houses
- Wet Wells
- Aeration Basins

the forced-main runs full, the less the likelihood of corrosion.

Some very old systems have very little MIC, even if they are gravity-flow systems. The daily load is sufficient to keep the pipes fairly full. This has a similar effect as seen in forced-main systems. Conversely, a new system may exhibit severe corrosion. This is a result of designing the system to handle anticipated volumes when the population density increases. Until such time, the lines rarely if ever experience full load conditions. The crown of the pipe in this scenario becomes highly susceptible to MIC.

Areas where sewage flow is slowed are at risk of MIC. Sewage fermentation continues regardless of flow rates. When the solid wastes are allowed to remain or collect in one area, the concentration of H_2S in the air space above the sewage increases. The higher H_2S concentration allows for more efficient proliferation of the microbes. As microbial proliferation increases, so does MIC. Gravity-flow lines and grit chambers are two such examples.

When the turbulence of the sewage increases, dissolved H_2S comes out of solution. This too increases the H_2S concentration above the sewage, leading to greater MIC rates. Drop manholes, pump stations, changes in plane within a line, and junction boxes are some examples.

The locale can have a significant

effect. Table I lists the environmental conditions most favorable for Thiobacillus growth. If one system is exposed to significantly warmer temperatures, the bacteria proliferate more efficiently than in a cooler climate. For example, a system in Vermont may see only 50 F (10 C) or more three months/year, while the same size system in Puerto Rico may never fall below 50 F (10 C). The Puerto Rico system will see significantly increased corrosion compared to the Vermont system.

Some locales have high levels of sulfur and H_2S in their water supply. Coastal areas may have chloride in the system. Farming communities will have phosphates and nitrates from fertilizers. Each of these scenarios creates an additional potential for MIC. Halophilic bacteria will generate HCl, while others utilize the phosphates and nitrates.

Table 3: Properties and Test Methods Specified for 65-Mil (1.5-mm) Coating

Property	Coating #1	Coating #2
Compressive Strength	C-579	D-695 (Property not needed)
Flexural Strength	C-580	D-790
Modulus of Elasticity, Flex	D-522	—
Tensile Strength	C-307/D-638	D-638
Tensile Elongation	D-638	D-638
Hardness	D-2240	D-2240
Bond	D-4542	D-4541
WVT/Permeability	D-1653	D-1653

Rehabilitation of a brick manhole—counterclockwise, from left top (p. 44): Brick manhole with severely deteriorated mortar joints; lined with cement-based epoxy repair material at approximately 1/4-inch (6 mm); being coated with rotary spray-applied epoxy at approximately 125 mils (3 mm); completed rehabilitation

Recently, the industry has seen a proliferation of coatings being touted for service in municipal wastewater systems. Some are coatings already in use in other industries. A manufacturer with little or no knowledge of the issues will then begin to recommend such systems for the severe environments of wastewater treatment plants. Other coatings were developed specifically for this market with full knowledge of the MIC process and application and cure challenges involved. Still others are copies of other manufacturers' products, offering no technology base other than some skill in cook-book blending. Specifiers of coatings and system owners have only a limited ability to evaluate the success of the many coatings available, much less the technology behind the coating or its chemistry—thus the need for strictly enforced specifications.

At this junction, some system owners and consulting engineers take a step down a slippery slope by asking their contractors to choose a coating. Sometimes the contractor even determines substrate repair and acceptability. As skilled as some contractors are, especially those who are SSPC-trained and certified, they are not qualified to make recommendations on matters needing a scientific background. When the contractor becomes the coating consultant, concerns about chemistry, materials science, corrosion science, microbiology, and civil engineering are ignored. Other issues, such as coating cost, ease of use, and personal/ business relationships become the overriding ones.

While cost issues and applicator friendliness are legitimate concerns, they are merely additional factors. When a coating is chosen by price alone, a prime responsibility of engineers and managers is compromised. A financial analysis that ignores cost/ unit area/year of service life is at best an analysis of questionable worth.

As for user friendliness, the author's experience has been that most coating manufacturers make coatings that are simple enough to allow for proper application easily. Failure to do so is tantamount to guaranteeing a poor sales growth. The problem in this regard usually relates to one of four factors.

- A preferred contractor or low-bidder does not have the required equipment.
- A preferred contractor or low bidder does not have the required skill levels or experience.
- The contractor does not have sufficient money in his bid to support materials of required/specified quality.
- The contractor does not have a preferred contractor discount available with the specified coating manufacturer.

Table 4: Compilation of Microbiological Species Identified in Environments Associated with Corrosion Fouling

Organism

Achromocacter Spp.
Aerobacter Spp.
    Aerobacter aerogenes
Alcaligenes
Bacillus Spp.
    Bacillus cereus
    Bacillus subtilis
Beggiatoa
Chromobacterium
Clostridium Spp.
Crenothrix
Desulfotomaculum Spp.
    Desulfotomaculum nigrificans
    Desulfotomaculum orientis
Desulfovibrio Spp.
    Desulfovibrio africannus
    Desulfovibriodesulfuricans
    Desulfovibrio salexigens
    Desulfovibrio vulgaris
Diplicoccus Spp.
    Diplicoccus pneumoniae
Escherichia Spp.
    Escherichia coli
    Escherichia freundii
Ferrobacillus ferrooxidans
Flavobacterium Spp.
    Flavobacterium hydrophilium
Gallionella ferruginea
Klebsiella Spp.
Klebsiella pneumoniae
Lactobacillus
Lepthothrix

Organism

Micrococcus
Microspira
Nocardia Spp.
Paracolobactrum Spp.
Proteus Spp.
    Proteus morganii
    Proteus vulgaris
Pseudomonas Spp.
    Pseudomonas aeruginosa
    Pseudomonas oleovorans
Salmonella Spp.
Sarcina Spp.
Shigella Spp.
Sphaerotilus
Spirillum
Sporovibrio
Staphylococcus Spp.
    Staphylococcus albus
    Staphylococcus aureau
    Staphylococcus citreus
Streptociccus Spp.
Thiobacillus Spp.
    Thiobacillus concretivorous
    Thiobacillus thiooxidans
    Thiobacillus thioparus
Thiothrix
Vibrio Spp.
Yeast
Fungi
    Cladsporium resinae
    Cephalosporium Spp.

Properties

Engineering consultants or system owners specify the properties of the materials to be used along with "appropriate" test methodology. Table 3 shows two different sets of engineering specified properties and the ASTM test methods used by their respective manufacturers.

Both are for a 65-mil (1.5-mm) spray-applied epoxy coating for manhole repair. The set of properties on the left is generated via ASTM methods predominantly under ASTM committees C-3, Committee on Chemical-Resistant Nonmetallic Materials, and D-1, Paint and Related Coatings, Materials, and Applications. The set on the right includes types of data generated via methods for molded plastics and preformed plastics under D-20, on plastics. "So what," you say. The method by which a given mechanical property is determined has a statistically profound effect upon the result. Factors such as sample shape, size, sample preparation, surface area/volume ratio, speed at which loads are applied, and the manner of testing all have an effect on the results obtained. The different ASTM methods utilize different testing techniques and sample preparation methods, and are unable to determine properties at a specific age. In addition, machining of samples introduces potential error due to the effect of frictional forces with a cutting device. This means that a particular property measured by a D-20 method will not necessarily correspond to the same property measured by a C-3 methodolgy.

Which methods are appropriate? We are dealing with a corrosion-resistant coating, not a molded or machined plastic part. Therefore, the methodologies of C-3 and D-1 pertain. Plastic test methods are wholly inappropriate and misleading. The properties requiring specification are those important to the performance in service. Let's examine some properties, needed values, and their appropriateness to their performance in service.

- Thickness—usually less than 125 mils (3 mm)— is an important property because some other properties are directly proportional to the thickness, e.g., wear, permeability, microbial barrier efficiency, and completeness of coverage. Thickness should *always* be specified as dry film thickness (DFT). On new, smooth concrete, a thickness of 30–40 mils (~1 mm) will work well. When the concrete is rougher than a 36-grit sandpaper, thickness needs to be increased to 60–120 mils (1.5–3 mm).
- Compressive strength—Since applied coatings in wastewater treatment systems are not subjected to more than minor levels of compressive forces, this property is not one that is truly needed. Its value lies in the fact that engineers think they understand its meaning and it is a cheap and easy test to run as a QC/QA test. But we are dealing with coatings, high-build paint, if you will. It makes no more sense to speak of the compressive strength of these coatings than it does for paint.
- Flexural strength—Since flexing and vertical misalignment occur regularly in buried wastewater treatment and collection systems, both the flexural strength and the tangent flexural modulus of elasticity are valuable properties to know. These can be accurately determined for coatings at thicknesses of 50 mils (1.2 mm) or greater. Values of 4,000 psi or greater for flexural strength and 5 x 10^6 psi or less for flexural modulus are good.

Tensile strength—One of the most important of mechanical properties, tensile strength is needed to calculate overburden-bearing capacity and is of paramount importance to resistance to ground water infiltration. Tensile strengths of 1,800 psi are considered excellent.

- Bond strength—The bond of the coating to the substrate is perhaps the key element to achieving a long service life. Loss of bond is the most common mode of failure for coatings. Bond strength to wet concrete should exceed the cohesive strength of the concrete, usually above 400 psi.
- Permeability—Calculated from water vapor transmission (WVT) rates and permeance, permeability is the property that controls passage of corrodents through the coating to the substrate. If all other properties and chemistry are equivalent, the coating exhibiting the highest permeability will typically fail first. A permeability of $<10^{-6}$ perm-inches is recommended.

Two other critical properties are chemical resistance and resistance to microbial growth. Since the chemistry in a sewer system is a true witches' brew, including microbe-generated sulfuric acid up to 60wt% and organic compounds, the chosen lining must possess excellent chemical resistance. Depending upon locale, other chemical species such as chlorides, nitrates, and phosphates may also be present.

It is also important for the coating to resist microbial growth. If the coating contains compounds that microbes can use, or if it is porous enough to allow microbes to penetrate, then the coating will fail prematurely. But one has to be careful in adding bacteriacides to wastewater treatment coatings. When the bacteriacide leaches, it will reach the WWTP. At the WWTP, the same SRB's are deliberately introduced in the digester in order to complete the degradation of suspended waste solids. Bacteriacides entering the WWTP will create havoc. Once the bacteriacides enter the digester, they kill off the deliberately introduced bacteria, thus reducing the efficiency of the digestion process. Further, since the WWTP processes will not remove or destroy the bacteriacide, they are discharged with the treated wastewater into waterways. This practice requires EPA approval and much testing.

Thus far, we have not discussed industrial wastewater treatment systems or municipal systems that allow pre-treated industrial waste. The concerns are the same as described heretofore with the additional corrosion potential represented by these discharges. Sometimes these industrial discharges destroy bacteria; sometimes they create conditions more favorable for bacteria proliferation; and, at other times, they create conditions favorable for different types of bacteria than the Th.

Each situation requires an analysis of the conditions present in order to make an appropriate coating recommendation. Some conditions may warrant a novolac epoxy, others a vinyl ester or some other coating chemistry.

For example, a treatment plant in western Virginia receives discharges from four chemical plants upstream of the treatment plant. Even though these discharges are partially pre-treated by the chemical companies, they still contain aggressive chemical species such as chlorides and organometal compounds. The combination of compounds dictates either an inorganic silicate refractory or a vinyl ester coating. The vinyl ester coating is more economical and was chosen in this case.

We have discussed aerobic bacteria and their role, but there are anaerobic microbes at work as well. For example, Desulfovibriodesulfuricans actually migrate through capillary and gel pores in the concrete to lodge on embedded reinforcement. These SRB use iron (Fe) to catalyze the reduction of polythionates to H_2SO_4. The H_2SO_4 is secreted directly on the iron and causes it to corrode and expand as it does. The volumetric expansion can be up to twelve times the original volume of the reinforcement. This expansion can generate tremendous stresses in the concrete, causing it to crack concurrent with the reinforcement. When this occurs, the reinforcement must be exposed, cleaned and repaired, grouted for stress relief at splices, and recoated with concrete. To coat the concrete without doing so is to virtually guarantee future failure. The concrete on both sides of the reinforcement needs to be repaired.

Although not specifically discussed in this paper, many microorganisms have been associated with corrosion, and the reader should be aware of them. Table 4 lists some of these microorganisms.

Coatings

Now we know what happened and why, and we have discussed needed physical properties, corrosion resistance, and substrate issues. It is time to consider coating types. For municipal collection systems without industrial discharge, a high quality bisphenol A epoxy cured with a cycloaliphatic amine or equivalent will perform admirably for many years. The author has personally inspected such linings in service for more than 20 years without any maintenance. Today, plural-component spray-applied polyureas are being used in a few municipalities. They have had adhesion problems due to the fact that they cure so rapidly that they cannot adequately wet the concrete and develop the needed adhesion. Some are not of sufficient quality to withstand hydrolysis—dissolution by water. Several companies are working on these problems with varying degrees of success. Polyurethanes are also being looked at for this application. Some coatings based on novolac epoxy resins are being installed. While these resins will resist higher concentrations of most acids, they do have a potentially serious drawback. Permeability testing shows that novolac epoxies are actually more likely to be permeable to H_2S than are bisphenol A epoxies.

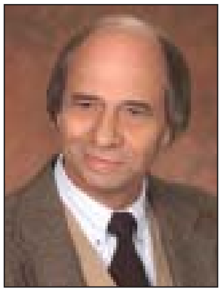
Conclusion

Wastewater collection and treatment systems present very difficult challenges to stakeholders such as owners, engineers, coatings manufacturers, and installers. This article has outlined some of these naturally occurring challenges. It is the responsibility of each of these stakeholders to become aware of these challenges and incorporate the necessary technology to withstand the difficult environments. The owner must ensure that cost/unit area/year of service is the determining factor in awarding bids. Owners need to be more judicious in contractor selection. Engineers need to become familiar with the conditions present and research available materials to ensure quality specifications. Engineers need also to apply their knowledge and skill in evaluating reported properties and test methodologies. Contractors need to develop the necessary skill set to apply the specified coatings or they should not be allowed to bid a project. Only an unwise contractor voluntarily places himself at risk by becoming the *de facto* consultant. He isn't being paid to take that financial risk or to risk civil penalties for failure. The coatings manufacturer has to know the exposure conditions, application and cure conditions, and required properties in order to develop a quality coating. He needs to have a knowledge of coatings chemistry and to be able to evaluate the effect of the environment upon the coating. The coatings manufacturer also needs to understand materials science in order to determine what properties are needed and to choose the correct methodology.

Short cuts lead to short coating service life.

Reference

1. G. Hall and G. Maloney, "Corrosion Rates of Uncoated Concrete for Selected Corrodents," *Journal of Protective Coatings & Linings*, December 1993, p. 61.



Gary R. Hall

Gary Hall is currently Manager of Organic Technology and Manager of Environment, Health and Safety at Sauereisen, Inc. (Pittsburgh, PA). Sauereisen manufactures ceramics, refractories, cements, and coatings. Mr. Hall is responsible for product development and improvement for Sauereisen and manages the Research and Development efforts for the organic product line. He has been with Sauereisen for 36-years and is a graduate chemist from the University of Pittsburgh. He is active in the National Association of Concrete Engineers, several ASTM Committees, American Institute of Chemical Engineers, and the Electrostatic Discharge Association. Mr. Hall is also a contributing editor for *JPCL* and has twice been the recipient of the *JPCL* Editors' Award. His areas of special interest include cement and concrete technology, corrosion science and control, polymer science, and nanotechnology.

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PRODUCTS FOR RESTORATION AND PROTECTION OF WASTEWATER INFRASTRUCTURES

LININGS – INFILTRATION AND CORROSION PROTECTION

SewerGard Epoxy Systems — No. 210

Self priming, moisture tolerant epoxy systems that are completely resistant to the micro-biologically induced corrosion common to municipal wastewater applications as well as provide an infiltration barrier. They are available in aggregate filled trowel (No. 210T) and rotary spray (No. 210RS) versions, as well as a fiber-filled airless spray version (No. 210S). The No. 210RS allows manholes to be efficiently lined from street level with minimal entry into the manhole. These products will bond to damp concrete and cure in the presence of moisture. An optional topcoat (210G) provides a more smooth surface for greater cleanability. This 100% solids product can be economically rolled or sprayed.

SewerSeal — No. F-170

Single component, high strength, 100% calcium aluminate based product for use in manholes and other wastewater structures. This material will restore structural integrity, prevent infiltration and resist mild acids and alkalies on concrete, brick, and steel structures. SewerSeal is designed for rotary and straight shot spray applications and can be applied at various thickness' in one pass.

H2OPruf — No. F-190

Two component cementitious based negative side waterproofing system specifically designed to withstand hydrostatic pressures that cause water seepage in below grade structures. Two 1/16-inch coats will withstand up to 70 feet of water head pressure. It can be applied by brush or spray, including rotary spray equipment used for manholes.

SUBSTRATE REPAIR

Underlayment and Repair Mortar — No. F-120

Single component, high strength, rapid set Portland cement based repair mortar that is available in trowel, castable and gunite grades. The trowel grade can be applied vertically and overhead and can be topcoated with epoxy in 5 hours.

Substrate Resurfacer — No. F-121

Single component, high strength, rapid set Portland cement based product for repairing, resurfacing, and waterproofing masonry structures. This material will restore structural integrity and prevent water infiltration into concrete and brick structures. It is designed for rotary and straight shot spray applications and can be applied at various thicknesses in one pass.

Filler Compound — No. 209

Three component, epoxy formulation that is specifically designed to fill voids, irregularities, and air pockets in concrete. No. 209 will provide a smooth surface ready for application of protective compounds in 3 hours. This material is also available in a fast setting grade that can be topcoated in 1 hour. Either formulation is suitable for application over damp or dry concrete. Application is performed with a rubber K&R trowel.

ACTIVE INFLOW AND WATERSTOP PRODUCTS

Manhole ChimneySeal — No. F-88

Elastomeric lining composed of fiber-reinforced, asphalt-modified urethane. Two component, chemical resistant seal that can be applied by a gloved hand onto the chimney sections of manholes to prevent water inflow. As a high solids elastomer, Chimney Seal maintains excellent elasticity and adhesion over a temperature range of -30ÐF to 250ÐF while resisting acids, alkalies, and salts.

InstaPlug — No. F-180

Rapid setting hydraulic water plug that will seal active water leaks and allow continuous rehabilitation work on concrete structures. This material will set in 60 – 90 seconds and cure completely in one hour. It is also used to fill small voids and for anchoring applications.

Hydroactive Polyurethane Grout — No. F-370

Catalyzed hydrophobic grout that reacts with moisture and expands to 20 times its volume to seal leaks, cracks, joints and voids. It bonds tenaciously to practically any substrate, wet or dry, it has excellent chemical resistance and it is safe for potable water.

SPECIALTY

PenePrime — No. 500

Two component water-borne epoxy primer that is specially formulated to work in conjunction with other Sauereisen products. PenePrime penetrates deep into the concrete substrate to seal porous substrates and reduce off-gassing from concrete. This product is manufactured to ensure maximum adhesion of the specified protective coating. Application is performed by brush, roll or spray.