biotech armor for concrete

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Mitigating the Corrosion of Concrete Pipe and Manholes

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Abstract: This paper deals with the problems of corrosion caused by sulfuric acid generated within sewer systems. The problems are identified and potential economical solutions are presented. There are four major ways to mitigate the corrosion of concrete pipe and manholes, due to sulfuric acid produced in a sewer system:

- Utilize Az design to elevate the alkalinity of the concrete.
- Coat or line the pipe and structure.
- Reduce the microbial induced corrosion (MIC), using computer model designs.
- Use acid-resistant cements and antibacterial additives.

The last two methods will be discussed at length because they are the most cost-effective means of extending the life of concrete in a sewer system. By reducing the generation of hydrogen sulfide and at the same time reducing the microbial activity in the system, MIC is effectively reduced. Also, by incorporating acid resistant cements and antibacterial additives, concrete in sewer systems will experience less or no corrosion; thus the life of the sewer system is extended.

Keywords: Microbial induced corrosion, Thiobacillus bacteria, hydrogen sulfide, antimicrobial, concrete pipe

Introduction

Environmental awareness, increased population densities, improved technology and fiscal restraint have combined to make MIC one of the major problems municipal engineers face today when designing wastewater systems. Rapidly increasing populations and population densities produce more wastewater for treatment. Our environmentally conscious society requires us to treat sewage so that it is harmless when the waste stream returns to our lakes, rivers and oceans.

This wastewater system requires a maze of piping, manholes, pump stations, and structures. Because of its strength and economy, concrete is one of the most widely used construction materials in this system. From a concrete-corrosion point of view, all these factors combine to give necessity for finding better solutions for reducing microbial induced corrosion (MIC).

In the area of wastewater design, the industry has made many advances over the last twenty years. Pipe manufacturers now produce pipe that is much more “water tight”. Very little sewage can escape out of the line and very little groundwater can infiltrate the pipe. The sewage is now more concentrated and more corrosive. Within the last decade, the ability to see inside an installed sewer pipe via remotely controlled closed circuit television has allowed engineers to actually view the results of ongoing MIC.

The current state of the infrastructure has encouraged municipalities to design their structures for maximum longevity. The Greater Houston Wastewater program represents one of the United States largest wastewater utilities [*1*]**.** Houston, according to the United States Environmental Protection Association 1992 Needs Report [*2*], reported that over 9,000,000 lineal feet of RCP needed to be replaced due to MIC. Currently, Houston is in the process of spending $1.9 billion to repair what is largely the result of MIC [*3*]**.** This story is repeated over and over in large and small municipalities around the world [*4*]**.** Engineers must design to combat MIC in order to increase the longevity of the sewer system and to make the system more economical and cost effective.

C.D. Parker in 1945 was one of the first to report the source of microbial induced corrosion (MIC) as the bacteria known as Thiobacillus [*5*]. This corrosion process is sometimes incorrectly referred to as hydrogen sulfide (H_2S) corrosion. H_2S alone is not corrosive to concrete whatsoever. It is the sulfuric acid (H_2SO_4) that is produced when the Thiobacillus bacteria metabolize the H_2S that actually corrodes the concrete. It is beyond the scope of this paper to detail the complete MIC cycle. For further information, the reader should see the ASCE Manual of Practice No. 69 [*6*].

When the wastewater steam is anaerobic (no oxygen is present), sulfate-reducing bacteria, existing in the slime layer in the invert of the pipe, convert the naturally occurring sulfates in the wastewater into H_2S. Numerous factors lead to greater H_2S production. It is a well-known fact that warmer temperatures result in more bacterial activity and greater H_2S production. Also, geographic regions with greater nutrients (B.O.D.) content in the water have a greater H_2S potential. The flow rate of the pipeline is a very significant factor as well. Lines with low or stagnant flows have a greater tendency to become septic and provide more anaerobic conditions for the production of H_2S. Greater flow rates help to introduce oxygen into the wastewater to prevent the system from becoming anaerobic. Higher flow rates also tend to clean away the slime layer to reduce the quantity of bacteria that can produce H_2S.

Released H_2S gas reacts with the moisture in the crown area to form dilute acids. The dilute acids reduce the pH on the surface of the concrete from its normal level of 11 or 12 to approximately pH 7 [fresh concrete pH measures approximately 12.5, but due to aging and natural carbonization, the pH level drops below 12.5 [*7*].

The Thiobacillus bacteria, which exists only at pH’s of 7 and below, further metabolizes the excess H_2S into H_2SO_4 (sulfuric acid). Successive generations of the bacteria continue to produce the acid and lower the pH to approximately 0.9. In practical terms, the cycle maintains a sulfuric acid concentration of approximately 5% to 10%. Once the pH drops below approximately 1.25, the H_2SO_4 corrodes the concrete by reacting with the calcium hydroxide of the cement that binds the sand and aggregate together [*8*]**.** It should be noted that MIC occurs in the crown area of the pipe above the water line. If the area below the water line is corroded, it is most likely erosion caused by excessive velocities or abrasive materials in the pipe. Corrosion below the water line could be caused by other acids and chemicals in the waste stream as well.

Presentationirst step in reducing and eliminating MIC is to design the wastewater collection and transmission systems to reduce to opportunities for H_2S production. One of the most significant design changes to occur in the last 18 years is the development of computer programs for sulfide and corrosion prediction. The most recent versions of these programs allow the user to analyze an entire system for sulfide generation and corrosion potential. When verified and calibrated, the model is a powerful tool which can be used to analyze the varying conditions anticipated throughout the life of the wastewater collection system. Using the manual method, this same analysis would require extensive time and severely limit the size of the project, which could be analyzed, and the detail of analysis, which could be performed. With a computer supported modeling technique, the model could be used as an Operations and Maintenance (O&M) tool. The impact of diversions, future flows, and changes in wastewater characteristics can all be analyzed before potentially costly decisions are made.

The most recent generation of programs published for sulfide generation and corrosion prediction are HS and Sulfide Works. Both were published in 1991. HS was developed through the American Concrete Pipe Association. Sulfide Works was developed by MicroComp Systems. Each program is provided with documentation and is based on the Pomeroy - Parkhurst Equations and the Corrosion Rate Predictive Model. The HS program is limited to pipes flowing partially full. This limitation requires manual input when modeling siphons or force mains. Sulfide Works' program handles either full-flowing pipes or partially full pipes.

When evaluating a system's sulfide potential, it may be necessary to simulate varied conditions. The programs provide various options, including constant or variable quantity or depth of flow and incremental life analysis, to account for variable flow quantities of depths during the sewer life, and will take into account the effect of input sulfide at junctions. For primary data input, sewage characteristics required are: climatic BOD, sewage temperature, design life [which may be broken into increments], acid reaction factor "k", pH of the sewage, upstream total sulfide level, insoluble sulfides, and the climatic ratio "c". The programs prompt for the number of reaches to be analyzed; then for the pipe diameter, slope and length of reach for each reach in succession, beginning at the upstream end of the sewer.

With the information provided by the software programs, and more specifically the "snapshot" information available from the ACPA Hydrogen Sulfide Prediction software, the designer can work with different "what if" scenarios to determine the best design for the wastewater system. These are important to the specific application, both at present and in the future.

Today's designer can have the modern day equivalent of a crystal ball, which allows the estimation of tomorrow's Operations, Maintenance, and Replacement (OMR) costs. H_2S Modeling Design Method software is used in estimating the future costs of wastewater systems. Pipe and all the other components of the wastewater system can be initially designed, rehabilitated or studied for future design and maintenance costs. Community expansion, real time and planned, can be accommodated by the H_2S Modeling Design Method program. Design professionals can utilize H_2S Modeling Design Method to determine future needs.

Deterioration of present systems can be determined prior to the system becoming a major problem. H_2S Modeling Design Method information is not only valuable at design time but also at rehabilitation time. Annual maintenance budgets can be accurately predicted by effectively utilizing the H_2S Modeling Design Method software on a periodic scheduled time frame. Design professionals can now have accurate input into wastewater system maintenance costs. Graphic presentations can be presented to city officials to support budget requests and to illustrate the construction and rehabilitation needs of the city's wastewater system.

As with any software of mathematical concept, H_2S Modeling Design Method is only as good as the data input. The accuracy of the data, and the skill and knowledge of the operator, are key factors in successful H_2S modeling.

Because the factors controlling sulfide generation in sewers are so complex, it would be unrealistic to expect that sulfide concentrations can be accurately predicted on an hour-by-hour basis. Even predictions of average sulfide conditions in a sewer are not considered precise, but they will be adequate for many design and operation purposes. The Pomeroy equations that have been devised have coefficients that can be modified to meet the objectives of the engineer, giving results that will approximate average performance of all sewers represented by any given set of parameters or that will give results in varying degrees of conservatism. Thus, a sulfide prediction may show a concentration that will rarely be exceeded in any sewer, or one that will be exceeded only part of the time, or one that will be an average value where septic conditions prevail. The level of understanding of sulfide generation mechanisms and corrosion of both cement bonded and ferrous materials allows a relatively accurate assessment of anticipated conditions in sewer systems and the cost-effective design of control measures. Structures, manholes, tanks and the treatment plants can benefit from the use of H_2S Modeling Design Method evaluation. This concept allows for the selecting of methods to minimize the corrosion of all concrete and metallic elements.

By utilizing the H_2S Modeling Design Method the following major factors can be addressed to minimize the formation and presence of sulfide in sewage systems.

- Limit the use of closed conduit systems [force mains, siphons, and surcharged sewers].
- Provide for velocities in both gravity and pressure pipes that are adequate to prevent deposition and accumulation of solids, especially during periods of low flow.
- Provide velocity in gravity trunk sewers and interceptors, such that surface re-aeration is adequate to prevent sulfide build-up.
- Eliminate direct discharge of sulfide to the wastewater collection system from industrial and septic waste sources.
- Minimize the accumulation of solids in the treatment plant at any location where they will become anaerobic and septic.

In addition numerous other methods are available to control the generation of sulfide in wastewater. These methods affect the oxygen balance in sewage, oxidize generated sulfide, and react chemically with dissolved sulfide to form insoluble sulfide, or affect the sulfide generation capability of the sulfate or organic sulfur reducing organisms. The methods include: 1) Oxygen injection in force mains, inverted siphons, U-tubes, hydraulic falls, and side streams; 2) chlorination; 3) hydrogen peroxide; 4) iron and zinc salts; 5) shock dosing with sodium hydroxide; 6) potassium permanganate; 7) sodium nitrate; 8) ozone; and 9) bacterial cultures and enzymes.

The second step in reducing and eliminating MIC is to prevent the Thiobacillus from growing, thus cutting off the biogenetic formation of sulfuric acid. Traditionally, efforts to control corrosion of concrete sewers have focused on coating the concrete or using plastic liners, or chemical treatments to reduce the concentration of dissolved hydrogen sulfide gas carried by the wastewater. Most of the treatments are costly and do not provide adequate, long-term protection or control. Concrete, which is coated, is not 100% effective. Acid can penetrate coatings though pinholes and react with the concrete; thus destroying the bond of the coating to the concrete [*9*]**.** Thiobacillus are still present and able to produce sulfuric acid on the surface of the coating. By adding an antimicrobial agent to the coating some of this action can be abated. Another concern about coatings is their adhesion to the concrete. Pull off testing of coatings has shown the failure zone within the concrete because the surface concrete pulls away with the coating. By increasing the cohesion of the concrete, greater resistance to coating pull off would be achieved. It stands to reason that fibers in the concrete would improve the concrete's cohesion and thus the coatings adhesion. For improved coating performance, the use of an antimicrobial agent in the coating and better adhesion through the use of fibers in the concrete is logical.

Another approach that has shown success in mitigating corrosion is mortar made from calcium aluminate cement and same source clinker. This material has shown a reduction affect on Thiobacillus growth and greater resistance to MIC although it is still subject to corrosion, albeit at a slower rate. Very recently new cements, which are acid resistant, have arrived in the market place which exceed the requirements of ASTM Performance Specification for Blended Cement (C1157M-95).

These cements can be used in place of portland cement and do not produce calcium hydroxide, which is attacked by sulfuric acid. They are made by blending fly ash with chemicals and are presently approved for concrete production under ASTM Specification for Ready-Mixed Concrete (C94-99).

Additionally, a new concept that has come into being is to damage the Thiobacillus cell growth by the use of an antimicrobial agent. Antibacterial materials have been in use for many years in products like "Dial Soap", which contains such material. Under today's government regulation, EPA regulates all such materials to be sure they are safe and nontoxic to humans, and other high-life forms. For years these materials have been used in antiseptic soaps and lotions for skin, disinfectant for medical instruments and for food and dairy equipment. The material, CONSHIELD™[1], being reported in this paper is a stable, quaternary, ammonium-salt derivative, which was developed at Emory University in Atlanta, Georgia for medical purposes. This material is water-soluble which makes it unique as an additive for concrete. It also can be applied in liquid form to a surface where a molecular bond is established. The other interesting feature of this material is that the chemicals in it are surface-active-agents and their antimicrobial activity is directed toward the bacteria cell membrane. By disrupting the membrane, the cell can not divide and thus it will die. Cell growth is binary. If one cell takes one hour to divide, after 24 hours there will be 16,777, 216 cells produced.

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[1] AP/M Permaform, 6250 NW Beaver, Suite 6, Johnston, IA 50131

With this material, testing commenced in June 1996, in the laboratories of Custom Biologicals, Inc., in Boca Raton, Florida. The investigative work was performed under the direction of Dr. Clarence L. Baugh. Dr. Baugh is well recognized in the field of microbiology, having published works dating back to 1959 and holds patents for Interferon Production and the Production of Mareks Disease Vaccine, among others. Wafers of concrete mortar were prepared by integral mixing of the antimicrobial solution with the mortar. Other untreated wafers were coated with the same solution. These samples along with plain (control) samples were forced to a lower pH≅ 8 using carbon-dioxide gas to accelerate the process.

A bacterial suspension of Thiobacillus thiooxidans, Thiobacillus thioparus, and Thiobacillus denitrificans were aseptically pipetted evenly onto the surface of concrete wafers and incubated at 25ºC for 24 hours. Viable counts were then obtained using a modified NETAC method (this is a method microbiologists use to determine cell counts). Four test replicates were made per set and incubated at 25ºC for 26 days. All of the organisms were killed by the test material with a complete kill of 24 hours. (See Table 1) In addition to the viable counts, a pH change did not occur and no growth was detected microscopically.

Table 1 – *Thiobacillus Inoculum Test Results*

Specimen	**Sample**	**Viable Count After 24 Hours**	**% Reduction**
T.denitrificans	Control	1×10^7	0%
T.denitrificans	CS In	1×10^2	99.999%
T.denitrificans	CS On	1×10^2	99.999%
T.thioparus	Control	1×10^7	0%
T.thioparus	CS In	1×10^2	99.999%
T.thioparus	CS On	1×10^2	99.999%
T. thiooxidans	Control	1×10^3	0%
T. thiooxidans	CS In	0	100%
T. thiooxidans	CS On	0	100%

From past experience the authors realized that laboratory results are indicators and real results have to come from the field or a working environment. With this in mind and because the laboratory results were very encouraging, field trials were undertaken.

The next step was to prepare samples for testing in a municipal sewer system. These samples were cores taken from concrete pipe commercially produced using the antimicrobial agent as an additive to concrete mix. The test protocol called for weighing the samples in a saturated-surface dry condition, and reading the initial sample surface pH. A sewer manhole was selected, which had very obvious corrosion taking place and very high H_2S reading. The samples were suspended three (3) feet below the manhole cover and approximately seven (7) feet above the flow line, and left there for three (3) months.

The original intention was to take readings of pH and weight loss after one year. At three- (3) month's time, a visual inspection was made just to check on the samples. Because of visible deterioration of the control samples, measurements were taken immediately instead of waiting for one year. The three- (3) month readings of pH and weight loss are shown in Table 2.

Table 2 – *In-situ Sewer Manhole Field Tests*

CONCRETE SAMPLES	**INITIAL**		**FINAL**		**WEIGHT LOSS (GRAM)**
	Weight (GRAM)	**pH**	**Weight (GRAM)**	**pH**	
Core from concrete pipe	894.3	11	891.4	3	2.9
Core from concrete pipe without additive	890.8	11	860.2	1	30.6

Based on the excellent preliminary test results, the City of Atlanta now specifies this material for all new and rehab cement in their sewer system. Other cities where it has been used in manhole rehabilitation are:

- Columbus, Ohio
- Ft. Walton Beach, Florida
- Mt. Prospect, Illinois
- Corsicana, Texas

Further testing in municipal sewer manholes is being conducted by Iowa State University using the antimicrobial material to further verify the initial test results.

After the tests were conducted using the additive, another option became available with the incidence of the acid resistant blended cement, further testing of sample in the manhole was conducted. Test results are shown in Table 3.

Table 3 – *In-situ Sewer Manhole Field Tests*

CONCRETE SAMPLES*	**INITIAL**		**FINAL**		**WEIGHT LOSS (GRAM)**
	Weight (GRAM)	**pH**	**Weight (GRAM)**	**pH**	
Acid resistant cement w/CS	539.4	11	539.1	3	0.3
Acid resistant cement	543.5	9	540.0	1	3.3
Plain Portland	470.0	9	446.1	1	23.9

(*) Suspended three (3) months in high concentration of H_2S gas.

Note the high degree of resistance to MIC that the combination of blended acid-resistant cement and the antimicrobial additive produced.

Conclusion

A well operating waste water system is essential to the health and well being of any society. Because the piping system is buried in the ground, it should last

forever once it is placed. Many sewer systems need upgrading because of undersize or deterioration of the piping. New technology is providing ways of doing some upgrading of existing piping, by insertion of liners, replacement by pipe bursting and shotcreting of large diameter pipe.

This paper has discussed two approaches for controlling MIC of concrete sewers.

1. New computer programs can be used to reduce the beginnings of MIC, i.e., the generation of hydrogen sulfide gas and subsequently corrosive sulfuric acid.
2. Early results with a new material, a stable quaternary ammonium salt derivative, added to concrete shows promise as a means of controlling bacterial growth on the concrete and reducing MIC.

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