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Xypex Chemical Corporation, V6V 2G9, Richmond BC, Canada

Two-prong approach to protect concrete in harshest environments

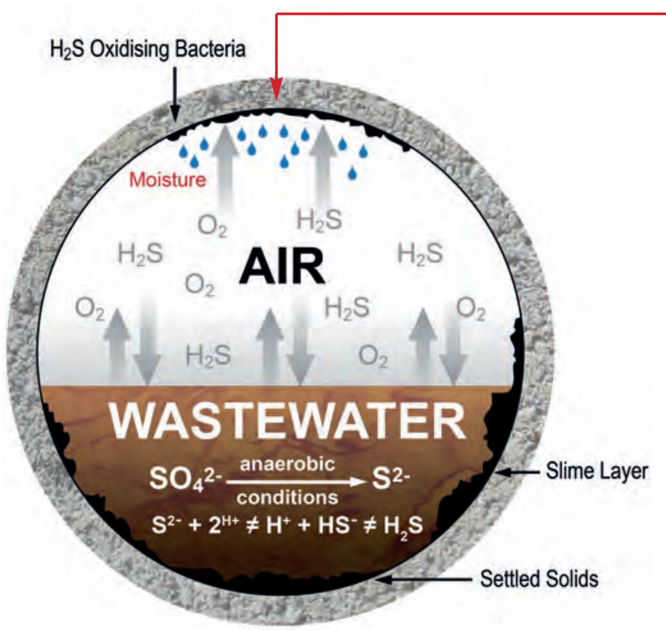
Dave Ross, Xypex technical services director, Canada

Acid-producing microorganisms are eating away some of the world's most important infrastructure at an alarming rate. Known as microbial induced corrosion (MIC), this complex bacterial process ultimately produces biogenic sulfuric acid that can steadily reduce the surface pH of concrete sewer system components to destructively low levels leading to rapid decay and potential collapse.

Many wastewater collection and treatment systems around the world are in need of repair or replacement because they have lost structural integrity due to MIC (fig. 1) and other forms of physical and chemical attack. The breakdown of wastewater infrastructure allows increased infiltration of runoff and groundwater and allows the leakage of wastewater into the environment along deteriorated conveyance systems and via overflows at treatment facilities.

In its 2016 Clean Watersheds Needs Survey, the U.S. Environment Protection Agency notes that of the $271 billion USD (about 235 Mrd. €) needed over the next 20 years to address deficiencies in U.S. publicly owned treatment works more than $51 billion (about 44 Mrd. €) is required for conveyance system repairs (i.e., Category III).

According to the report, "the pattern of increasing Category III needs shows that communities are increasingly planning to ensure the structural integrity of the nation's existing conveyance system infrastructure, correct infiltration and inflow



$$H_2S + 2O_2 \xrightarrow{\text{Bacteria}} H_2SO_4 \longrightarrow \text{Corrosion}$$

Microbial Induced Corrosion

Slow flow and long retention times in a sanitary sewer are the precursor to microbial induced corrosion in sewer and wastewater treatment structures. During transit time, dissolved hydrogen sulfide (H_2S) is produced in the waste flow liquid by sulfate-reducing bacteria under anaerobic conditions. Hydrogen sulfide gas is released into the sewer atmosphere by turbulence and dissolves in the moisture and slime on the sewer crown.

Bacteria turn the sulfur compounds into sulfuric acid which attacks the concrete by means of acidic corrosion and longer term through expansive sulfate attack. This causes the concrete to slowly corrode and self-destruct.

Fig. 1: Microbial induced corrosion (MIC) is a complex biochemical process that ultimately results in the production of highly acidic conditions that can rapidly deteriorate concrete and metal.

(I/I) problems, and correct problems related to sanitary sewer overflow." Of the $51 billion (about 44 Mrd. €) needed for repairs, more than $42 billion (82%) (about 36 Mrd. €) is needed for projects to reinforce and/or reconstruct structurally deteriorating sanitary or combined sewers, and the remaining $9 billion (about 8 Mrd. €) is needed to correct I/I problems, including projects to control the penetration of water into sanitary or combined sewers from the ground, drains, storm sewers and other improper entries.

It has been reported that Western Europe water and wastewater utilities, which supply drinking water and sanitation services to 390 million people across 17 countries, are expected to invest nearly 90 Mrd. € (about $103 billion) over the next five years to rehabilitate water and wastewater infrastructure.

With so much replacement and repair work on the books, owners and specifiers are challenged to find ways to prevent deterioration from reoccurring and to protect against MIC using modern construction methods.
Preventative measures commonly used to protect concrete sewer system infrastucture such as precast reinforced concrete pipe (RCP), manholes, cast-in-place lift stations, headworks and other structures from accelerated corrosion and failure include:

- Corrosion resistant liners and coatings such as PVC and HDPE liners and epoxy and cementitious coatings
- PVC pipe as a replacement for smaller concrete pipe
- Durable Concrete mix design to reduce permeability, and enhance resistance to chemical attack
- Waste stream treatments and chemical additives - to reduce hydrogen sulfide levels (e.g. oxygen/air injection, or addition chemicals such as hydrogen peroxide, chlorine, potassium permanganate, calcium nitrate, sodium hydroxide, or magnesium hydroxide)
- Antimicrobial additives – can be added to concrete at time of batching or applied later

While there are many approaches to providing MIC protection, there are limitations for each that need to be considered by owners and design professionals. For instance, liners and coatings do provide visible protection against acid and sulfate attack; however, these options can be expensive and time-consuming to install in existing structures. If not installed properly, they may also be subject to failure.

Plastic liners, for example, are particularly sensitive to the quality of site welded seams. Both liners and coatings can be forced off the surface by hydrostatic pressure. Coatings must be carefully applied to avoid pinholing, which can be a challenge in dry-cast pipe mixes. PVC pipe has advantages, but is limited to smaller diameter pipes only. Waste stream additives can be expensive and cumbersome to install and maintain.

For existing structures, solutions for repair of MIC damage are more limited, and include:

- Repair mortars followed by corrosion resistant epoxy coatings
- Corrosion resistant repair mortars
- Cured-in-place pipe relining – may include many different pipe repair and renewal techniques
- Repair mortars with antimicrobial additives
- Waste stream chemical treatment additives – following repair

One of the major limitations of these strategies are the very difficult working conditions that may be present in existing sewers that need quality surface preparation and thorough drying prior to application of moisture sensitive materials such as epoxy.

Enhancing concrete durability

There are various ways to increase the resistance of concrete to acids and other forms of chemical attack. Diffusion or penetration of aggressive substances into concrete through interconnected capillary pores and cracks can lead to degradation and deterioration of the structure. Depending on the nature of the diffusive substances, they can attack concrete or its steel reinforcement. By blocking the pores and healing cracks, the mass-transfer rate into the concrete can be decreased thereby enhancing the concrete's durability and the longevity of the structure's service life.

Traditional means for improving the durability of concrete are through reduction of the water/cement ratio (W/C) and by increasing the moist curing time. Another way to increase concrete durability and other factors is through the partial replacement of Portland cement with supplementary cementitious materials (SCMs) such as fly ash, ground granulated blast furnace slag (GGBFS), and silica fume.

The addition of these materials has been shown to improve the durability and longevity of concrete structures. However, it is important to evaluate the source of SCMs because their quality and performance can vary greatly, particularly when it comes to fly ash. In addition, silica fume can be difficult to work with as it can make concrete sticky and, in some cases, prone to cracking.

Crystalline waterproofing

Another time proven method of increasing the durability of concrete structures is through the use of crystalline waterproofing technology. This technology can be used as an admixture or cementitious coating to reduce the permeability and increase the durability of concrete by filling and plugging pores, capillaries and micro-cracks with a non-soluble, resistant crystalline formation. Most causes of deterioration need these paths and passages in order to diffuse into the concrete. This form of waterproofing technology reacts with the byproducts of cement hydration to plug the pores, capillary tracts and micro-cracks with a crystalline formation (figs. 2 & 3). The infiltration and diffusion of liquids and gases is significantly reduced, which protects concrete from the effects of acid, sulfate, and chloride attack.

Fig. 2: Here, Xypex crystalline waterproofing begins to fill in a pore in this concrete matrix.

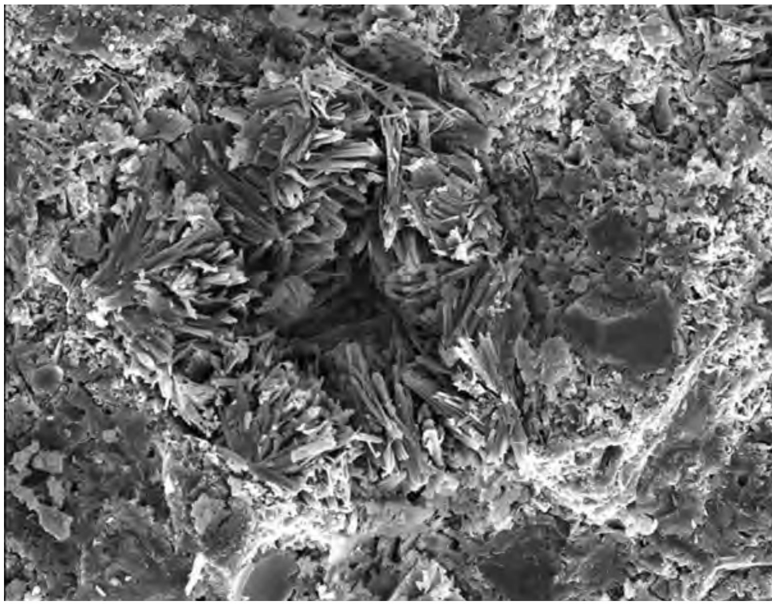


Fig. 3: In this photo, the crystalline formation completely fills the pore preventing the infiltration or exfiltration of moisture and potentially damaging diffusion substances.

Antimicrobial innovation

Xypex Chemical Corp., of Vancouver, Canada, has provided a family of crystalline waterproofing and protection products since 1970 and distributes its products through a service network in more than 80 countries. Recently, the firm introduced a new dual-protection product called Xypex Bio-San C500 that combines crystalline waterproofing with a mineral-based antimicrobial that kills the Thiobacillus group of bacteria species responsible for microbial induced corrosion.

Xypex Bio-San C500 is manufactured in the form of a dry powder that is added to the concrete at the time of batching. It can be added manually or through a computer controlled batching system. It can also be added directly to the mixer in central mixer plants or directly to the ready mix truck prior to adding the balance of the materials in a dry-batch plant operation

Xypex Bio-San C500 provides concrete precasters and ready-mix producers with a single, convenient product that can be added to any project or product that requires a high level of corrosion resistance, waterproofing and antimicrobial protection. Bio-San antimicrobial components are fixed in a mineral matrix that becomes an integral part of the concrete. The antimicrobial ingredients work indefinitely to destroy harmful bacteria at a cellular level by releasing metallic ions that open holes in the bacteria's cell membrane and destroy the cell from the inside out. It cannot be washed off or wear out.

Bio-San cast in a key role

The Roaring Fork Club is an exclusive 383-acre private club located in the town of Basalt, Colorado, USA. Located about 20 minutes from the world-renowned ski resort of Aspen, the club was built in the late 1990s and includes many amenities such as golf, fishing on the Roaring Fork River and other family sports and wilderness activities.

Recent development plans call for the construction of 13 new, larger cabins as well as a 43 unit employee village and this expansion is now underway. Wastewater treatment for the expansion project will be provided by the Basalt Sanitation District by means of a gravity sewer extension. Civil engineering for the expansion is being provided by Sopris Engineering LLC, a locally owned and operated firm that provides consulting, civil engineering and land surveying services.

An eight-inch PVC collection line will be used to service the cabins and employee village and gravity fed to a 14-foot tall lift station buried below grade and equipped with grinder pumps that will feed a 500-foot long pressure sewer line to connect with a Basalt Sanitation District main sewer line.

Sopris design engineer Paul Rutledge notes that his firm's design for the sewer system to serve the club expansion specified Xypex Crystalline Waterproofing from the very beginning. "When you are designing a lift station for sewage the key questions is how can we design this station so that it will hopefully last forever, particularly knowing that it will be cast-in-

Fig. 4: The newly cast-in-place lift station is part of the sewer system supporting an expansion at the exclusive Roaring Fork Club in Basalt, Colorado, USA. Xypex Bio-San C500, a crystalline waterproofing and antimicrobial admixture, was added to the ready-mix concrete used to pour the new lift station. An 8-inch PVC inflow line (see inset photo) can be seen entering the lift station on the right and a 2-inch outflow pipe exits on the left.

Fig. 5: An 18-inch thick base pad is poured for the new lift station.

Fig. 6: A 10-inch thick lid with access hatches is cast in place.

place concrete that will be subject to a hostile hydrogen sulfide environment and varying pH levels."

Rutledge notes that in the past the firm would have probably considered an epoxy coating for the interior of the lift station; however, that option is no longer the first choice. "Before we knew about concrete admixtures like Xypex, we would have specified an epoxy or some other coating for a lift station or manhole where we needed extra protection," he explains. "With Xypex waterproofing and now with Bio-San antimicrobial, the protection becomes an inherent part of the structure. It not only heals cracks and stops leakage it inhibits slime growth."

The cast-in-place lift station (fig. 4) at Roaring Fork Club measures 14' tall, 12' wide and 14' long with 12-inch thick walls, an 18-inch thick base (fig. 5) and a 10-inch thick lid (fig. 6). The body of the lift station includes three below grade level penetrations to allow for the eight inch PVC inflow pipe, a two-inch outflow pipe, and a four-inch access for control and power lines The 12'x14' lid includes surface penetrations for a manhole access, pump and supplemental access ways.

The lift station structure required approximately 42 cubic yards of ready-mix concrete, which was provided by United Companies, a provider of ready-mix throughout western Colorado. The Xypex Bio-San C500 was delivered in 50 lb.

(22.7 kg) buckets to United Companies to be added to the concrete headed to the Roaring Fork Club pour. Xypex Bio-San C500 was added at 1% by weight of total cementitious materials.

"The choice of Xypex Bio-San was relatively easy since we had already specified Xypex waterproofing admixture," Rutledge says. "I shared the information on the benefits of using the new Xypex Bio-San at one of our progress meetings with the development team. I told them we have an opportunity, right now, to use a state-of-the-art product and they approved its use." He adds, "By using the Xypex Bio-San we eliminate the need for any supplemental coatings inside (fig. 7) or out. We eliminate the need to coordinate a separate coating contractor and any delays or special preparation that might have been required. This protection is built into the structure and eliminates a lot of concerns. For instance, installing bolts through an epoxy coated surface is one concern that's eliminated. We can bolt on the interior ladder, the fiberglass base for the pumps and other hardware without any worries."

An exfiltration hydrostatic test (fig. 8) was performed on the lift station after sufficient curing time. Penetrations were blocked and the lift station was filled to the top with water and monitored for seven days – no leakage is allowed. "The test on the Roaring Fork lift station was exceptionally successful," Rutledge notes. "On our first test, there was virtually no water loss at all so no repairs were needed, which makes our lives that much easier. The fact that you have a structure that won't leak, will self heal any cracks, and inhibits slime growth – that's going to provide long-term savings in maintenance and longevity. No one wants to be digging up a sewer structure in 10 years because it has prematurely deteriorated or have to get inside and recoat it because a superficial coating has failed."

Lift station repairs planned

On the banks of the Arkansas River, about six hours southeast of the Roaring Fork Club, lies the rural city of Lamar, Colorado, with a population of about 8,000 residents. Lamar relies on a wastewater system composed of 56 miles of collection lines ranging in size from 6" to 24", three lift stations on the east edge of the city, and one main pumping station to pump wastewater into treatment lagoons.

The city completed a new main lift station in early 2011 to replace a preexisting lift station that had reached the end of its useful life. Unfortunately, the new lift station has experienced accelerated corrosion due to high levels of hydrogen sulfide (H_2S) gas emitted from the sewage stream. Microbial induced corrosion has eroded the interior of the lift station to the extent that up to two inches of concrete can be easily scraped off, particularly in the wet well at the lowest part of the structure.

According to Adam Teunissen, PE, a project manager for JVA, Inc., an engineering firm based in Boulder, Colorado, "The original structure is less than ten years old, yet it is experiencing a very rapid corrosion rate - the most I've ever seen in my career." JVA has been hired by Lamar to repair the corroded lift station wet well and attempt to counter the root cause of the corrosion - unusually high levels of H_2S and microbial induced corrosion.

"We have recommended that the surface damage within the lift station be repaired with Xypex Megamix II with Bio-San, which is a new repair mortar designed specifically for situations where MIC is involved," Teunissen explains. "We also plan to knock down the levels of H_2S gas in the system by introducing Bioxide at different points in the wastewater stream."

Fig. 7: Looking down into the newly cast-in-place lift station, a key part of the wastewater infrastructure that will support a major expansion at the exclusive Roaring Fork Club in Basalt, Colorado, USA.

Fig. 8: Hydrostatic testing was successful on the first attempt.

Dual protection for repairs

Xypex Megamix II with Bio-San is a new resurfacing mortar that is formulated with Xypex crystalline waterproofing technology in combination with Bio-San bioactive mineral solids. In this way, Megamix II with Bio-San provides chemical resistance to acid, sulfate, and chloride, waterproofing, limits MIC, and replaces lost section thickness all in one product.
It is quickly applied by shooting or hand application, trowels easily and does not require elaborate procedures such as surface drying needed for most coatings.

“We believe that the use of new Megamix with Bio-San is the best option for this situation,” Teunissen says. “There will be less surface preparation than what would be required for an epoxy or other coating material. And, the city has already applied an epoxy coating when the rapid deterioration was first discovered, but it failed very quickly. I have used regular Megamix when I was with another company and it saved us time and money and worked well. By using Megamix with Bio-San, we will save time and money again and achieve greater MIC resistance, particularly when combined with the Bioxide we’ll be adding to the waste stream.”
As part of the post-repair monitoring program, JVA intends to mount treated and untreated concrete cylinders inside the wet well area and check them periodically to measure the effectiveness of Megamix II with Bio-San.

This will not be the first time that the product is evaluated in such a “hot” H_2S environment. In an independent study of the antimicrobial effect of Xypex Bio-San C500, the active ingredient was added at 1% by weight of Portland cement mortar and compared to untreated control samples. The sample cylinders were suspended in a wastewater facility that was chosen due to elevated levels of H_2S (about 50 ppm) over a period of 10 years. The exposure trials showed that treated samples had nine times less concrete mass loss compared to the untreated control samples. Bacterial concentration on the treated samples was minimal, even after 10 years of exposure.
“We were somewhat concerned about the unusually high levels of H_2S in the system, which are far higher than the 50 ppm that the Bio-San test data is based on,” Teunissen notes. “However, we believe we’ll be able to get that level down to 50 ppm or lower using Bioxide, and that Xypex with Bio-San will take care of the rest.”

FURTHER INFORMATION

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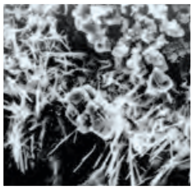

Xypex Crystallization
(Initiated)

Xypex Crystallization
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Xypex Bio-San C500 is a uniquely designed admixture for integral, long-term protection of concrete in harsh sewage conditions with high levels of H_2S that cause microbial induced corrosion. Bio-San C500 combines potent antimicrobial protection along with the unique crystalline technology of the Xypex Admix C-Series. Bio-San C500 prevents microbial induced corrosion, stops infiltration/exfiltration of water, and provides acid and sulphate resistance, significantly extending the service life of concrete sewage collection systems and waste water infrastructure.

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