TECHNICAL NOTE

TECHNICAL INFORMATION FROM THE CONCRETE PIPE ASSOCIATION OF AUSTRALASIA

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BIOGENIC SULPHURIC ACID ATTACK ON CONCRETE PIPE

In concrete pipes carrying aged sewage, in warm climates, the interior surface above the effluent level is subject to attack by sulfuric acid generated by bacterial action at the pipe wall, making use of hydrogen sulfide gas in the sewer atmosphere. The production of hydrogen sulphide and the consequential deterioration of concrete sewer pipes is first and foremost a function of sewer design and environmental factors. This process, known as "H_2S attack", can lead to very rapid deterioration.

Biogenic sulphiric acid (BSA) attack is regarded as one of the most aggressive forms of attack on concrete sewer infrastructure. This has been studied since 1945 when it was discovered that bacteria are responsible for the attack mechanism. Colonisation of the concrete surfaces is progressive with various strains of the same family, Thiobacilli, thriving at different pH levels. The final stage is the most aggressive, with acid producing bacteria thriving at pH levels less than 2 and being capable of generating sufficient acid to reduce the pH to 1, which is highly aggressive to all cementitious materials.

The mechanism for this type of attack on concrete is summarised below:

Step 1: Newly installed concrete pipe has a highly alkaline surface pH of approximately 12-13. In the wastewater, sulphate reducing bacteria (SRB) reside which utilise sulphates present in the wastewater as an oxygen source, reducing them to produce hydrogen sulphide (H_2S) and CO_2.

Step 2: If there is sufficient oxygen, nutrients and moisture present, colonisation of neutrophilic bacteria, can cause oxidisation of H_2S to create sulphuric acid (H_2SO_4). The acid reacts with the concrete pipe obvert and walls, and further lowers the pH. This facilitates colonisation by new strains, adapted for lower pH conditions, and so the pH gradually decreases.

Step 3: When the pH of the concrete falls to around 4, colonisation by aggressive acidophilic bacteria occurs. These bacteria are capable of generating enough sulphuric acid to reduce the surface pH to 1-2 which is considered highly aggressive to all cementitious materials.

Step 4: The corrosion process now results in concrete mass loss. The sulphuric acid first reacts with the calcium hydroxide ($CaOH_2$) in the concrete to form gypsum. The formation of gypsum is associated with an increase in volume by a factor of 1.2 to 2. Furthermore, the reaction between gypsum and tri-calcium aluminate (C_3A) with the formation of ettringite causes an even larger volume expansion, which leads to increase of internal pressure and deterioration of the concrete matrix.

The factors that influence this type of attack to occur include:

- Hydrogen sulphide being generated
- The release of H_2S from a water phase to a gaseous phase
- Biological oxidisation of H_2S to sulphuric acid above the wastewater surface
- Acid attack on the damp surfaces of the exposed interior surface of the concrete pipe

However, not all concrete pipes will be affected by hydrogen sulphide problem. The physical factors that that may impact on the affect sulphide generation and corrosion include:

- Concentration of organic material and nutrients in the sewerage.
- Sulfate concentrations.
- Dissolved oxygen level in the sewerage.
- pH value (i.e. lower pH increases likelihood of H_2S growth and attack).
- Temperature (i.e. higher temperature increase likelihood of bacterial growth rate).
- Relative humidity (corrosion requires moisture on the pipe wall).
- Stream velocity, surface area to volume ratio, vertical drop points, detention time.
- Level of construction, grit and debris, surcharging.
- Turbulence (at the point of turbulence, the water surface area for gas transfer increases often leading to a dramatic release of H_2S to the gaseous phase)

Whilst all these factors have an important role in contributing to the corrosion impact on concrete pipe in sewerage wastewater, good design, specification and manufacture, can help to mitigate the onset and the severity of sewer corrosion.

Extensive field and laboratory research has shown that corrosion is significantly reduced under the following operating conditions:

- High slopes in the network
- High dissolved oxygen content
- High wastewater pH
- Surcharging of sewer networks
- Short sewer reaches
- High concrete alkalinity
- Moderate operating temperatures

Over the years considerable efforts have been dedicated to the understanding of the corrosion process, and how to better deal with this form of corrosion. BSA is a complex process and there is much conjecture in the literature surrounding the critical level of H_2S concentration required to start the process, and significant knowledge gaps appear to exist particularly concerning concrete mix design. The test methods and parameters used have varied considerably.

It is generally well known that blended cements containing slag (GBS), fly ash, Microsilica or silica fume, provide improved durability and increased resistance to chemical attack. In the late 1990's CPAA member companies along with BRANZ and Auckland University developed a laboratory based sulphuric acid (inorganic or mineral) methodology to measure the relative laboratory attack rates on various Portland cement mixes. This research work was completed in 2001 and indicated a superior laboratory performance of GBS blends.

More recent research started in 2001, and still ongoing, is indicating that BSA attack is much more aggressive than chemical sulphuric acid generally used in laboratory testing. This research indicates that relative lab mineral acid resistance of various cement blends is not a reliable indicator of field performance under field biogenic conditions, with the environment determined by the cement structure being considered to be an important parameter. The BSA mechanism reduces the pH level down to severe levels with some cements and blends allowing different critical levels and acid production rates. The result is that all cements and blends are equally vulnerable to rapid corrosion.

Recommendations

There are many factors that come in to play when determining how severe the internal exposure conditions of concrete sewer pipes will be. It is vitally important that designer understand what level of performance they are expecting from the concrete, and how best to adapt the product to the conditions.

Recent research has indicated that there is no recognised cement blend (slag, silica fume, etc.) that can effectively resist biogenic sulfuric acid attack particularly when extremely high acidic environments ($pH < 1.0$) develop inside a concrete sewer pipeline.

However, blended cements can be an excellent mechanism to provide durability provision against sulfate attack (as opposed to sulfuric acid attack), chloride exposure, or acidic effluent, for external pipe wall protection.

It is recommended by the CPAA that when designing concrete sewers to resist severe H_2S attack mechanism, that designers consider alternative solutions for the interior of the pipe to deal with the aggressive nature of this environment. This can include utilising the following durability provisions:

- Increasing the total alkalinity of the concrete using appropriate materials
- Increasing the cover of the concrete pipe, or including a sacrificial layer of concrete that won't impact on the structural or durability design requirements over time.
- Specifying a keyed-in plastic liner over the interior surface of the pipe to protect it from H_2S attack.
- Using concrete made with antimicrobial additives