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Research article

DEACTIVATION OF SULFIDE OXIDIZING BACTERIA TO PREVENT SEWER CORROSION, COLLAPSE AND EXPLOSION

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Abstract

It is natural phenomena that hydrogen sulfide, H_2S, is evolved from wastewater stream in underground pipelines by anaerobic bacteria and then the H_2S is oxidized to sulfuric acid, H_2SO_4, by sulfide oxidizing bacteria, thiobacillus, and the H_2SO_4 naturally creates sewer corrosion, collapse and explosion. Many scientists, engineers and government's sewering agencies are well aware of the disasters, but no one presented a real solution until today except temporary solutions for few hours, few weeks or few months. It is known to the public that an estimated $14 billion is spent in the U.S. alone,[1,2] to prevent sewer corrosions. Over 40 years of R&D, through chemical theories and equations with full scientific and persistent experiments, successfully invented a new chemical mix which can be used as a semi-permanent basis. **Copyright © IJACSR, all rights reserved.**

Keywords: Deactivation, Acidithiobacillus, Sewer, Corrosion, Prevention

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Introduction

Many countries in the world have underground sewer pipelines which carries wastewater. The H_2S evolved from wastewater is oxidized to H_2SO_4 by sulfide oxidizing bacteria. The H_2SO_4 corrodes sewer pipes and eventually collapse sewer pipes. The most current technology, since 1994, to prevent sewer corrosion in the U.S. is to spray sodium hydroxide, NaOH, or 50 to 60% slurry of magnesium hydroxide, $Mg(OH)_2$, but these chemicals are not only expensive, but also last only 2 to 3 months or 7 to 9 months, respectively. Equation Nos. 1 through 22 of this manuscript are the chemical theories for the causes of sewer corrosion and eventual collapse and deactivation of sulfide oxidizing bacteria, which are formulated in Equation No. 23. Section 4.1 through 4.8 describes persistent experiments and the findings which are summarized in Figure 6.

It is theoretically and technically possible to insert plastic lining inside the wastewater flowing sewer pipe for prevention of sulfide corrosion, but it is economically prohibitive.

Materials and Method

1. OCCURRENCE OF HYDROGEN SULFIDE CORROSION

As shown in Figure 1[3,4], the sulfate ion (SO_4^{2-}) naturally occurs in water supplies and in sewage as well. Sulfates are reduced to sulfide and to hydrogen sulfide (H_2S) by bacteria under anaerobic condition of sewer pipe. The H_2S is then biologically oxidized to sulfuric acid (H_2SO_4).

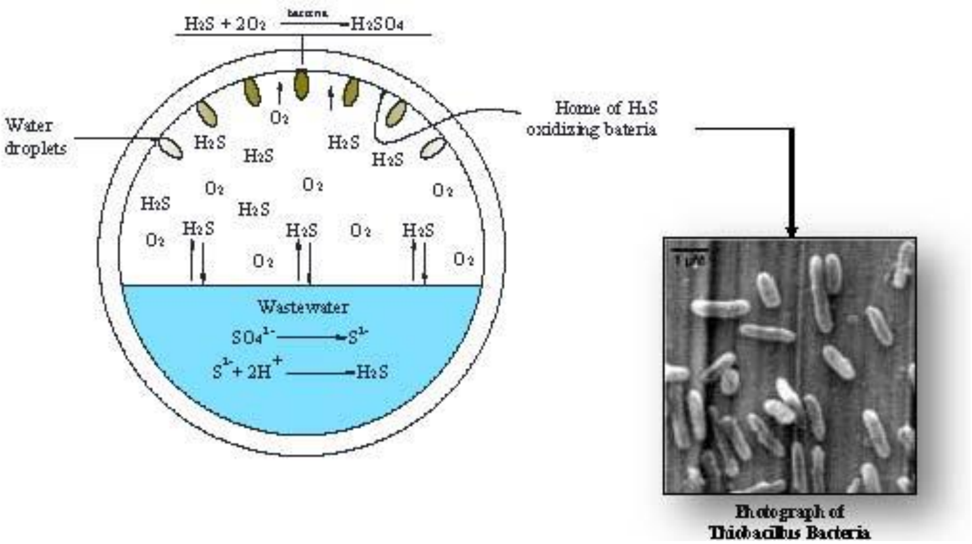


Figure 1: Sewer Corrosion due to H_2S Oxidation

SO_4^{2-} + [Organic matter] H_2S -------------------- (1)

$H_2S + 2O_2$ H_2SO_4 ------------------ (2)

OR

In gas stage: $H_2S \longleftrightarrow HS^- + H^+$ -------------- (3)

$HS^- \xrightleftharpoons[\text{Anaerobic Condition}]{\text{Bacteria}} H^+ + S^{2-}$ -------------- (3-1)

$$\xrightarrow[\text{Bacteria, thiobacillus}]{H_2S\ \text{Oxidizing}}$$

Details of process occurring in sewer pipes under sulfide buildup conditions are shown in Figure 2[5,6]. In sewers, made of materials to acid such as concrete, iron or steel, the acid formation can lead to corrosion and destruction of sewer crown and eventually collapse the sewer pipe at the low pH of 2.0 (plus or minus) condition.

Most sulfide is formed by bacteria living in a matrix of filamentous microbes and gelatinous material coating on the submerged walls of wastewater pipes that is often referred to as the slime layer. The bacteria producing sulfide are strict anaerobes and, consequently, live beneath the water surface in gravity sewers and on the pipe walls in force mains. The bacteria may also thrive in sludge and grit deposits found along the bottom of pipes. In order to produce sulfide compounds, the bacteria require a source of sulfur and a food supply. Sulfate, SO_4, generally abundant in wastewater, is usually the common sulfur source, though other forms of sulfur, such as organic sulfur from animal wastes, can also be reduced to sulfide. The dissolved organic material prevalent in the wastewater provides an ample food supply for the bacteria to flourish. The overall sulfide and sulfuric acid formation mechanism is illustrated in Figure 2.

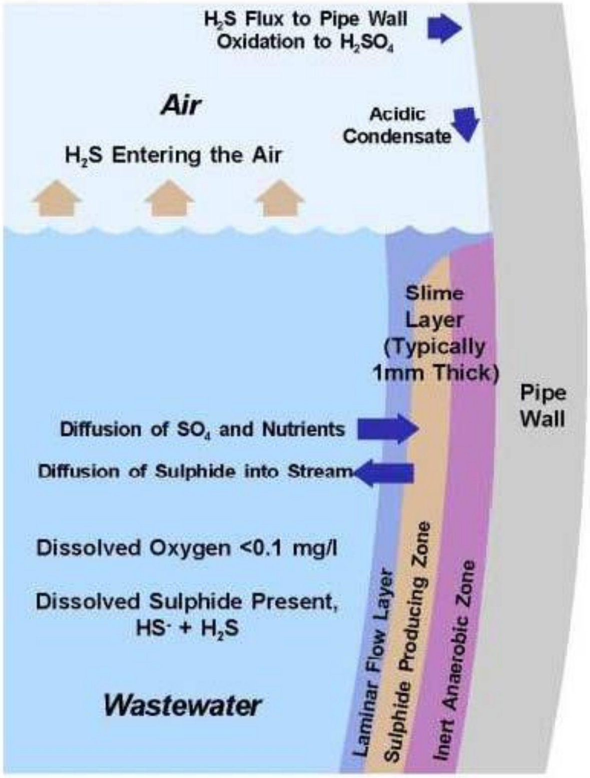
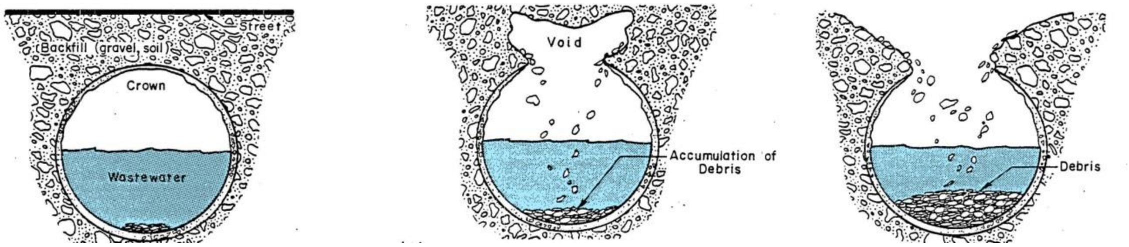


Figure 2: Overall Corrosion Mechanism in Wastewater Pipelines (from ASCE, 1989)

Presence of hydrogen sulfide can cause rapid and extensive damage to concrete and metal sewer pipe. Figure 3[7,8,9] shows the mechanism of sewer failure due to hydrogen sulfide corrosion.



(A) Corrosion reduces structural integrity of pipe crown.

(B) Crown collapses and voids forms from backfill washing into sewer.

(C) Backfill continues to wash into sewer blockage and/or street collapse.

Figure 3: Process of Sewer Failure due to Hydrogen Sulfide Corrosion

The crown spray process was first invented by Dr. Edward Esfandi[10] in 1986. Sicne 1994, 50% to 60% magnesium hydroxide, $Mg(OH)_2$, alone has been used by public agencies in the U.S. to deactivate the sulfide oxidizing bacteria, thiobacillus, which lasted only 7 to 9 months[1, 11].

Conventional mechanism of the crown spray process to inhibit sewer corrosion is shown in Figure 4 [11, 12].

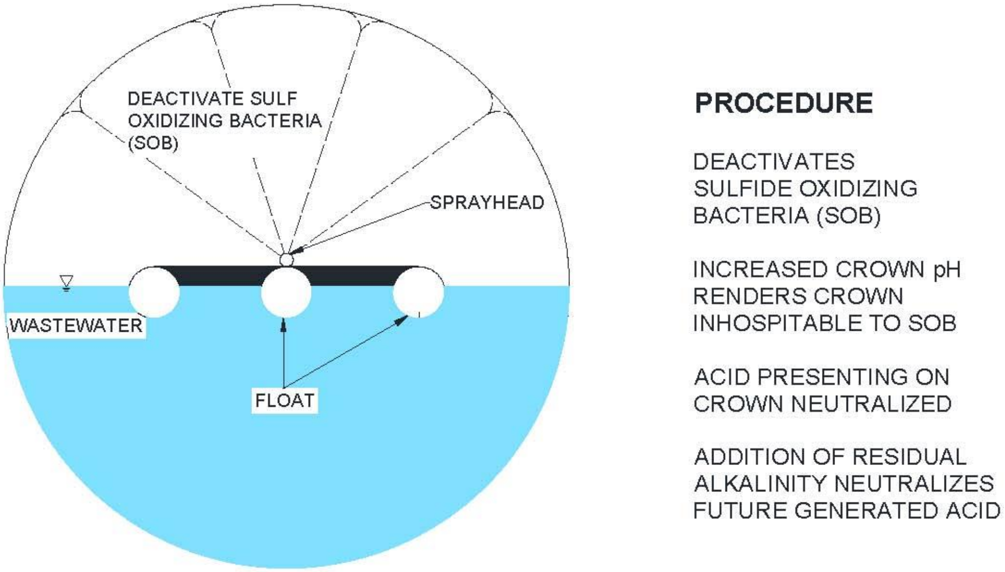


Figure 4: Crown Spray Process to Inhibit Sewer Corrosion

2. RESEARCH & DISCUSSIONS ON DEACTIVATION OF SULFIDE OXIDIZING BACTERIA

2.1. Rate of H_2S Production vs. pH

Extensive research has been done on corrodibility of sewer pipe under conditions that hydrogen sulfide, H_2S, develops in sewer pipes[13,14,15]. For this research, the chemistry of H_2S, characteristic of sewer corrosion and invention of new chemical(s) for prevention of sewer corrosion must be clearly understood. It is important to know the amount of H_2S escape (flux) from the wastewater to the sewer atmosphere in the sewer pipe.

Properties of H_2S and HS^- in dissolved sulfide fraction in wastewater are function of pH, as shown in Equation Nos. 1 and 3, i.e.,

$$H_2S \quad \leftrightarrow \quad HS^- + H^+$$

$$\frac{[HS^-][H^+]}{[H_2S]} \quad = \quad K_1$$

$$Log\,\frac{HS^-}{H_2S} \quad = \quad -Log\ H^+ \quad + \quad Log\ K_1 \text{ --------------------- (4)}$$

$$= \quad pH \ - \ pK_1 \quad \text{where } pK_1 \approx 7.0 \text{ (Ionization Constant)}$$

Therefore, it is necessary to investigate the amount of H_2S that can be produced and fluxed to air space of sewer pipe at different pH levels.

a) At pH = 2.0

From Equation No. 4,

$$Log\,\frac{[HS^-]}{[H_2S]} \quad = \quad pH \ - \ pK_1 \qquad \text{------------------------------ (5)}$$

$$= \quad 2.0 \ - \ 7.0$$

$$= \quad -5.0$$

$$\frac{[HS^-]}{[H_2S]} \quad = \quad Anti\,Log\,[-5.0] \quad = \quad 0.00001$$

$$[HS^-] \quad = \quad 10^{-5}\,[H_2S]$$

therefore,

$$\frac{[H_2S]}{[H_2S]+[HS^-]} + \frac{[HS^-]=10^{-5}\,[H_2S]}{[H_2S]+[HS^-]} \quad = \quad 1\,(total)$$

$$\frac{1.00001[H_2S]}{[H_2S]+[HS^-]} \quad = \quad 1$$

$$\frac{[H_2S]}{[H_2S]+[HS^-]} \quad = \quad \frac{1}{1.00001} \quad = \quad 0.99999 \qquad \text{------------------------- (6)}$$

(Portion of H_2S in the air space of sewer pipe is almost 100% @ pH = 2.0)

b) At pH = 5.0

From Equation No. 5,
$$Log\frac{[HS^-]}{[H_2S]} = 5.0 - 7.0$$
$$= -2.0$$
$$\frac{[HS^-]}{[H_2S]} = Anti\,Log\,[-2.0] = 0.01$$
$$[HS^-] = 10^{-2}\,[H_2S]$$

therefore,
$$\frac{[H_2S]}{[H_2S]+[HS^-]} + \frac{[HS^-] = 10^{-2}\,[H_2S]}{[H_2S]+[HS^-]} = \frac{1.01[H_2S]}{[H_2S]+[HS^-]} = 1$$
$$\frac{[H_2S]}{[H_2S]+[HS^-]} = \frac{1}{1.01} = 0.99 \quad \text{---------------------------------} \quad (7)$$

(Portion of H_2S in the air space of sewer pipe is 99% @ pH = 5.0)

c) At pH = 7.0

From Equation No. 5,
$$Log\frac{[HS^-]}{[H_2S]} = 7.0 - 7.0$$
$$= 0.0$$
$$\frac{[HS^-]}{[H_2S]} = Anti\,Log\,[0.0] = 1.0$$
$$[HS^-] = [H_2S]$$

therefore,
$$\frac{[H_2S]}{[H_2S]+[HS^-]} + \frac{[HS^-] = [H_2S]}{[H_2S]+[HS^-]} = \frac{2[H_2S]}{[H_2S]+[HS^-]} = 1$$
$$\frac{[H_2S]}{[H_2S]+[HS^-]} = \frac{1}{2} = 0.5 \quad \text{--------------------------------------} \quad (8)$$

(Portion of H_2S in the air space of sewer pipe is 50% @ pH = 7.0)

d) At pH = 9.0

From Equation No. 5,

$$Log\frac{[HS^-]}{[H_2S]} = 9.0 - 7.0$$

$$= 2.0$$

$$\frac{[HS^-]}{[H_2S]} = Anti\,Log\,[2.0] = 1.0\times10^2$$

$$[HS^-] = 1.0\times10^2\,[H_2S]$$

therefore,

$$\frac{[H_2S]}{[H_2S]+[HS^-]} + \frac{[HS^-]=100[H_2S]}{[H_2S]+[HS^-]} = \frac{101[H_2S]}{[H_2S]+[HS^-]} = 1$$

$$\frac{[H_2S]}{[H_2S]+[HS^-]} = \frac{1}{101} = 0.0099 \quad \text{------------------------------ (9)}$$

(Portion of H_2S in the air space of sewer pipe is only 1% @ pH = 9.0)

e) At pH = 10.0

From Equation No. 5,

$$Log\frac{[HS^-]}{[H_2S]} = 10.0 - 7.0$$

$$= 3.0$$

$$\frac{[HS^-]}{[H_2S]} = Anti\,Log\,[3.0] = 1.0\times10^3$$

$$[HS^-] = 1.0\times10^3\,[H_2S]$$

therefore,

$$\frac{[H_2S]}{[H_2S]+[HS^-]} + \frac{[HS^-]=1000[H_2S]}{[H_2S]+[HS^-]} = \frac{1001[H_2S]}{[H_2S]+[HS^-]} = 1$$

$$\frac{[H_2S]}{[H_2S]+[HS^-]} = \frac{1}{1001} = 0.00099 \quad \text{--------------------------- (10)}$$

(Portion of H_2S in the air space of sewer pipe is only 0.1% @ pH = 10.0)

f) At pH = 13.0

From Equation No. 5,

$$Log \frac{[HS^-]}{[H_2S]} = 13.0 - 7.0$$

$$= 6.0$$

$$\frac{[HS^-]}{[H_2S]} = Anti\,Log\,[6.0] = 1.0 \times 10^6$$

$$[HS^-] = 1.0 \times 10^6\,[H_2S]$$

therefore,

$$\frac{[H_2S]}{[H_2S]+[HS^-]} + \frac{[HS^-] = 10^6\,[H_2S]}{[H_2S]+[HS^-]} = \frac{(10^6+1)\,[H_2S]}{[H_2S]+[HS^-]} = 1$$

$$\frac{[H_2S]}{[H_2S]+[HS^-]} = \frac{1}{10^6+1} = 1.0 \times 10^6 \approx 0 \text{ ------------------ (11)}$$

(Portion of H_2S in the air space of sewer pipe is none @ pH = 13.0)

The above analyses indicate that H_2S hardly exist in the air space of sewer pipe at pH of 9.0 or greater. The sulfide oxidizing bacteria, thiobacillus, actively thrive at pH level of 2.0 plus or minus to corrode pipes. Therefore, the purpose of this research is aimed to invent or develop chemicals which can deactivate sulfide oxidizing bacteria, thiobacillus.

2.2. Logarithmic pH vs. Concentration Diagram of H_2S

From Equation Nos. 4 through 11, it can be seen that the H_2S flux doesn't thrive at pH ≥ 9.0. Because the pHs of wastewater in sewer pipes are 7.0 plus or minus, the active H_2S in the air space of sewer pipe can contribute to the sewer corrosion is about 50%. However, from Equation Nos. 3 and 3-1, the HS^-, the portion of produced H_2S, in the air space of sewer pipe can be disassociated to H^+ and S^{2-}. In order to find out the fate of H_2S in the air space at different level of pH, the relationship between H_2S, HS^- and S^{2-} must be identified. The relationship existing between H_2S, HS^- and S^{2-} at various pH levels are shown in Figure 5[16,17]. As seen in Figure 5, at pH values of 7 (pK_1) and above, most of the reduced sulfide exists in solution as HS^- and S^{2-} ions, and the amount of free H_2S is gradually reduced towards almost none at pH level of ≥ 13.0 (pK_2). At pH levels of ≤ 7.0, the equilibrium shift toward the formation of unionized H_2S/[aq] is -Log 3.5 which is about 54% of total sulfide (S_T) (see Equation No.20-1 and Fig. 5). The bacteria, called thiobacillus, capable of oxidizing H_2S to sulfuric acid, H_2SO_4, are ubiquitous in nature and are always present on the crown (internal top surface) of sewage pipes. Because of the aerobic conditions normally prevailing in sewers above the wastewater, the thibacillus bacteria oxidize the H_2S to H_2SO_4, and the later, being a strong acid, attacks the concrete. A logarithmic pH – concentration diagram for H_2S with ionization constants, $pK_1 = 7.0$ and $pK_2 = 13.0$ (See figure 5) can be illustrated as below.

Total Concentration, $S_T = [H_2S] + [HS^-] + [S^{2-}]$ -- (12)

or
$$\frac{S_T}{[H_2S]+[HS^-]+[S^{2-}]} = 1 \qquad \text{-------------------- (13)}$$

$$\frac{S_T/[H_2S]}{[H_2S]/[H_2S] + [HS^-]/[H_2S] + [S^{2-}]/[H_2S]} = 1 \qquad \text{--------------------- (14)}$$

(@ pH ≤ 7.0) (@ pH = 7.0 to 13.0) (@ pH ≥ 13.0)

$$\frac{S_T/[H_2S]}{1 + [HS^-]/[H_2S] + [S^{2-}]/[H_2S]} = 1$$

Because $H_2S \leftrightarrow HS^- + H^+$ (see Equation No. 3)

$$\frac{[HS^-][H^+]}{[H_2S]} = K_1$$

$$\frac{[HS^-]}{[H_2S]} = \frac{K_1}{[H^+]} \qquad \text{--- (15)}$$

From Equation No. 3-1,

$$HS^- \leftrightarrow H^+ + S^{2-}$$

$$\frac{[H^+][S^{2-}]}{[HS^-]} = K_2$$

Then,
$$K_1K_2 = \frac{[H^+]^2[S^{2-}]}{[H_2S]}$$

$$\frac{[S^{2-}]}{[H_2S]} = \frac{K_1K_2}{[H^+]^2} \qquad \text{--- (16)}$$

From Equation Nos. 15 and 16, Equation No. 14 becomes:

$$\frac{S_T/[H_2S]}{1 + K_1/[H^+] + K_1K_2/[H^+]^2} = 1$$

then, $$[H_2S] = \frac{S_T}{1 + {K_1}/{[H^+]} + {K_1K_2}/{[H^+]^2}} \qquad \text{-------------------------------- (17)}$$

(@ pH ≤ 7.0) (@ pH =7.0 to 13.0) (@ pH ≥ 13.0)

Similarly, divide Equation 13 by [HS$^-$], then,

$$[HS^-] = \frac{S_T}{{[H^+]}/{K_1} + 1 + {K_2}/{[H^+]}} \qquad \text{-------------------------------------- (18)}$$

Similarly, divide Equation 13 by [S^{2-}], then,

$$[S^{2-}] = \frac{S_T}{{[H^+]^2}/{K_1K_2} + {[H^+]}/{K_2} + 1} \qquad \text{---------------------------------- (19)}$$

However, the primary purpose of this research is to find relationship between H_2S vs. pH of Equation No. 17,

(a) pH ≤ 7.0 i.e., $pH \le pK_1 \le pK_2$

From Equation No. 17, $$Log\,[H_2S] = Log\,S_T - Log\left\{1 + \frac{K_1}{[H^+]} + \frac{K_1K_2}{[H^+]^2}\right\} \qquad \text{--- (20)}$$

$$\frac{d\,\{Log[H_2S]\}}{d\,pH} = 0 \qquad \text{-- (20-1)}$$

* (If pH ≤ 7.0, slope of H_2S = 0, ---- See Figure 5)
* Equilibrium composition: pH ≤7.0; pH_2S = -log3.5 = -54% of total S_T

(b) pH between 7.0 and 13.0 i.e., $pK_1 < pH < pK_2$

From Equation No. 17, $$Log\,[H_2S] = Log\,S_T - Log\,{K_1}/{[H^+]}$$

$$= Log\,S_T - pH + pK_1$$

$$\frac{d\,\{Log[H_2S]\}}{d\,pH} = -1 \qquad \text{-- (21)}$$

* (If pH = 7.0 to 13.0, slope of H_2S reduces by tangent 45° ---- See Figure 5)
* Equilibrium composition:
pH between 7.0 to 13.0; pH_2S = declines from -log3.5 @ pH=7.0 to –log9.6 @ pH=13.0, i.e., H_2S declines from -54% to -98% of total S_T.

(c) pH > 13 i.e., $pK_1 < pK_2 < pH$

From Equation No. 17,

$$Log\,[H_2S] = Log\ S_T - Log\left\{\frac{K_1K_2}{[H^+]^2}\right\}$$

$$= Log\ S_T - 2\,pH + pK_1K_2$$

$$\frac{d\,\{Log[H_2S]\}}{d\ pH} = -2 \qquad \text{--} \ (22)$$

* (If pH ≥ 13.0, slope of H_2S drastically reduces by tangent 63.43° ---- See Figure 5)

* Equilibrium composition:

pH ≥13.0; pH_2S = declines from -log9.6 @ pH=13.0 to –log11.5 @ pH=14.0, i.e., H_2S declines from -98% to -100% (none)

Similar calculation can be applied to plot Equations 18 and 19, but most important species in this research is Equation 17 and from Equations 20, 20-1, 21, 22 and Figure 5, it is evident that unionized H_2S diminishes as pH level increases. From the above theoretical analyses, it can be concluded that the sulfide oxidizing bacteria, thiobacillus, can be deactivated at higher level of pH of 13.0 or greater, i.e., the H_2S, which corrodes sewer pipe, can hardly exist at pH level of 13.0 or greater.

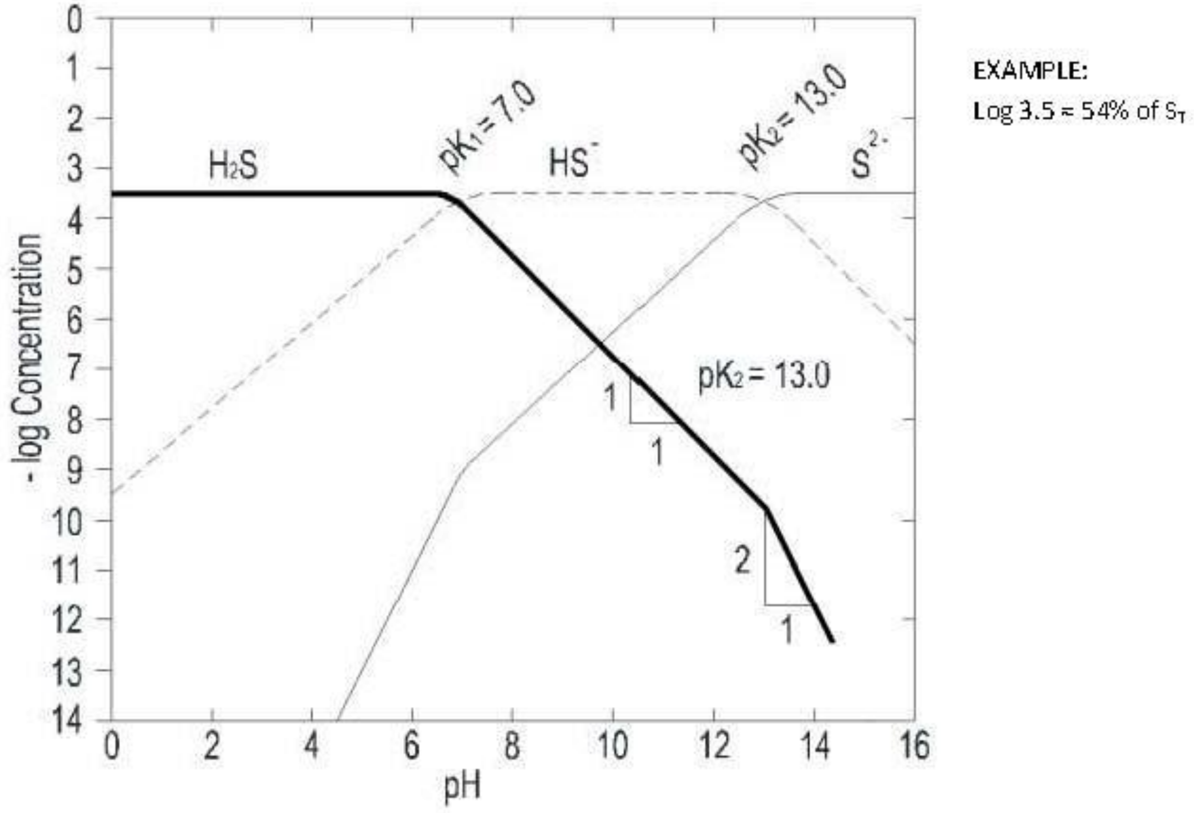


Figure 5: Equilibrium diagram of H_2S Concentration – pH dependence

2.3. Rate of Concrete Pipe Corrosion

The corrosion of concrete pipe is depended on (1) production of H_2S in sewer water, P_s, (2) turbulence of flow, t_f, (3) velocity of flow, V_f, (4) H_2S flux from the wastewater to the air space of the sewer pipe, f_s, at different pH, (5) fraction of H_2S absorbed by concrete, F_{H_2S} grams of H_2S/m^2/year, which means that the more H_2S is absorbed by the concrete surface the greater the corrosion rate, (6) alkalinity of concrete surface, A, which is reversely proportional to the rate of corrosion, and (7) other unknown factors, [K]. Therefore, the corrosion rate, C, can be formulated to:

$$C \quad = \quad P_s t_f V_f \, f_s \, [K] \frac{F_{H_2S}}{A} \qquad \text{-------------------------------} \qquad (23)$$

There are also daily cycles from velocity, detention time and wastewater characteristics, etc. However, the major factors in Equation No. 23 are the fraction of H_2S absorbed by concrete, F_{H_2S}, and alkalinity, A, of the concrete crown surface and it was found through a long term research that factors 1 and 4, P_s and f_s, proportionally affect factor 5, F_{H_2S}, while factors 2 and 3, t_f and V_f, adversely affect factor 5, F_{H_2S}. Also, it is reminded that the factor f_s is depended on the pH of wastewater in sewer pipe as shown in Section 3.1 above. The factor [K] may also include temperatures of wastewater and the roughness of the crown of the sewer pipe, moisture content of air space, etc., but most likely constant, i.e., $[K] \approx 1$.

In Equation No. 23, the effect of turbulence creates additional air-water interfaces in comparison with a slow stream. The factor, velocity of flow, affects the thickness of the slime layer (Figure 2), as well as the ability of the stream to transport solids in the wastewater.

3. LABORATORY EXAMINATIONS OF THE SELECTED CHEMICALS

3.1. Name of Chemicals Selected and Dilution Rates with Water

During the past 40 years, various chemicals, near 100, were examined to find most effective chemicals to deactivate, defy or resist against the sulfide oxidizing bacteria (SOB), thiobacillus, for prevention of sewer corrosion. The chemicals finally selected are: Mixture of Magnesium Hydroxide and Titanium Dioxide, $[Mg(OH)_2 + TiO_2]$, $Mg(OH)_2$, TiO_2, $Al(OH)_3$, $Ba(OH)_2$ and $Ca(OH)_2$. The selection of above 5 chemicals was based on non-toxic, lower water solubility and higher density.

In order to avoid confusion on the percentages of chemical mix, the % dilution of each chemical with water for the laboratory experiments must be clearly defined as follows.

"A" = [50 to 60%, by vol., of $Mg(OH)_2$] + [40 to 50%, by vol., of water] = 100% slurry, ready to coat

"B" = [50 to 60%, by vol., of TiO_2] + [40 to 50%, by vol., of water] = 100% slurry, ready to coat

"C" = [50 to 60%, by vol., of $Al(OH)_3$] + [40 to 50%, by vol., of water] = 100% slurry, ready to coat

"D" = [50 to 60%, by vol., of $Ba(OH)_2$] + [40 to 50%, by vol., of water] = 100% slurry, ready to coat

"E" = [50 to 60%, by vol., of $Ca(OH)_2$] + [40 to 50%, by vol., of water] = 100% slurry, ready to coat

"F" = 50% NaOH as liquid state

3.2. Mixture of “A”, “B” and “F” (see Section 4.1 for Definition of “A”, “B” and “F”)

The addition of “F” (50% NaOH) is only a few drops until the pH increases to 13.0 or greater. Then, this mixture was coated with a thickness of 2 millimeters (mm). Consequently, the life time of both, with and without “F”, reached in the neighborhood of 60 months plus and 50 months plus, respectively, i.e., the preventative coating was not attacked by H_2SO_4, and the sulfide oxidizing bacteria, thiobacillus, was deactivated during the 60 months plus and 50 months plus, respectively.

Life time expectancy of application using “A”, “B” and “F” is greater than 60 months plus and 50 months plus while that of application using “A” alone, which is the current technology, is only 7 to 9 months, i.e. the life time can be extended more than approximately 7 times longer.

3.3. Mixture of “A” and “F”

The mixture of “A” and “F” was coated on the internal top surface of the concrete pipe and concrete block which was dipped in the H_2SO_4 solution (pH= 2.0 plus or minus). Consequently, the life time of coating with “A” and “F” reached in the neighborhood of 15 to 16 months.

3.4. Mixture of “B” and “F”

The mixture of two (2) chemicals, “B” and “F”, was coated on the internal surface of the pipe and concrete block, with a coating thickness of 2mm, which was dipped in the H_2SO_4 solution (pH = 2.0 plus or minus). Consequently, both of the life times of coatings with “B” alone and with the mixture of “B” and “F” reached 50 months plus.

3.5. Mixture of “C” and “F”

In only 3 to 5 months after the coating, both with and without addition of “F” were intruded by H_2SO_4 solution.

3.6. Mixture of “D” and “F”

In only 3 to 4 months after the coating with and without addition of “F”, both sides of coated internal surface of concrete pipe and concrete block were intruded by H_2SO_4 solution.

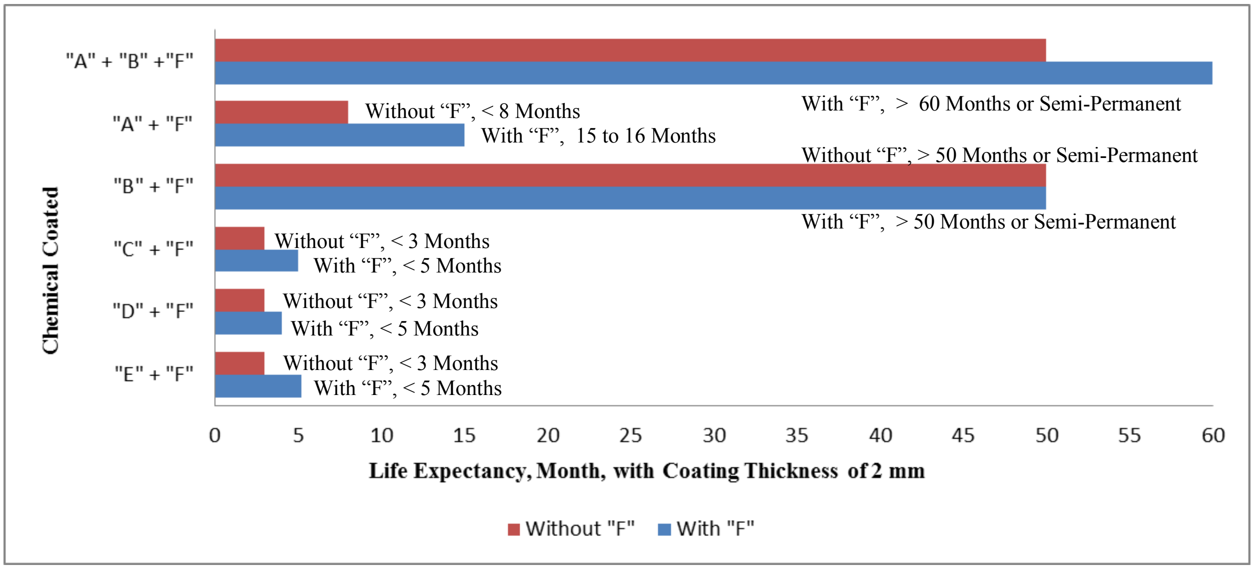
3.7. Mixture of “E” and “F”

In only 3 to 5 months after the coating with and without addition of “F”, both sides were intruded by acidic solution.

Results and Discussion

Results of the long-term research and laboratory experiments indicate that life expectancies are shown in Figure 6.

Without “F”, > 50 Months or Semi-Permanent



* Note: For “A”, “B”, “C”, “D”, “E” and “F”, refer to Section 4.1 for names for chemicals

The thickness of the coated chemical for this research and development was 2 mm while the thickness of the coated chemical, 50 to 60% slurry of $Mg(OH)_2$, “A”, alone, coated by a public agency in the U.S., is 4 mm to 6 mm[10,12]. Therefore, if the thickness of the newly developed chemical is 4mm to 6mm, the life expectancy could be much longer than double or semi-permanent.

Conclusion

In concluding this long-term research, Figure 6 shows the result of the research, i.e., the best chemical mix for prevention of sewer corrosion is the mixture of “A” and “B” with “F” as explained in Section 4.2. Alternately, the second best chemical mix is the mixture of “B” and “F” as explained in Section 4.4.

Acknowledgement

During 1973 to 1993, Dr. Edward Esfandi and other co-workers of the Los Angeles County Sanitation Districts contributed their time and effort for investigation of sewer corrosion, eventual collapse and explosion. In 1991, MIT invited me to present the status of the on-going research on sewer corrosion. During 1993 to the current, research chemists of the RCH Research & Environmental Laboratories, Inc. and Standard Testing and Engineering, Inc. (STE) assisted this research and difficult laboratory experiments. At the final stage of this research, Dr. Joseph Devinny and Dr. James Lu, emeritus professors of University of Southern California and Ronald Latanision of MIT reviewed and commented to complete this manuscript. I deeply appreciate it to those co-workers’ and professors’ help and assistance. Also, Professor Dudley Herschbach, Nobel Prize Winner in Chemistry, Harvard University, strongly encouraged me to publish it after his review and comment. In addition, Eric Hong of STE helped well-organized preparation of this manuscript.

References

[1] Esfandi, Edward, Ph.D and Roger Sydney, “Control Concrete Sewer Corrosion via the Crown Spray Process”, Water Environment Research, Volume 68, Number 3.

[2] Cloevis, Advanced Water Management Center, The University of Queenland, Australia, 12/28/2012.

[3] Steel, E.W., University of Texas and Mc, T.J., Tulane University, “Water Supply and Sewerage”, Fifth Edition, Chapter 14, McGraw Hill Book Co., 1979.

[4] Wells, T., Melchers, Robert E. and Bond, P., Centre for Infrastructure Performance and Reliability, The University of Newcastle, Australia and Advanced Water Management Centre, The University of Queenland, Australia, “Factors Involved in the Long Term Corrosion of Concrete Sewers”.

[5] Rhee, C.H., Ph.D, P.E., Los Angeles County Sanitation Districts, Lecture Note of “Corrosion Effect Caused by Industrial Wastewaters” at Massachusetts Institute of Technology, Cambridge, Massachusetts, Oct. 1991.

[6] Apgar, D., Coprincipal Investigator, Washington State, Whiterspoon, J. and Easter, C., Technical Director, CH2M HILL, 2007.

[7] US EPA, “Hydrogen Sulfide Corrosion in Wastewater collection and Treatment Systems”, Report to U.S. Congress, Office of Water(WH-595), Washington D.C., May 1991.

[8] Awwa Manual M27, “External Corrosion – Introduction to Chemistry and Control”, Awwa, Denver, CO, 1987.

[9] MMS, CMOM – “Commercial and Residential FOG, corrosion, and Sewer Maintenance Personnel and Pretreatment Personnel Communication, July 2003.

[10] Esfandi, Edward, Ph.D., Los Angeles County Sanitation Districts, “Proposal to Conduct Research for Control Sewer Corrosion”, 1986

[11] Jenifer James, P.E., Los Angeles County Sanitation Districts, “Control Sewer Crown Corrosion using the Crown Spray Process”, U-TECH Underground Technology, Sept 2004.

[12] James, Jenifer, P.E., “Control Sewer Crown Corrosion Using the Crown Spray Process”, THE FREE LIBRARY, 21, 983, 564 Article and Books, Sept 2004.

[13] Guan, S.W., Ph.D., Madison Chemical Industries, Inc., Milton, Ontario, Canada, “Corrosion Protection by Coatings for Water and Wastewater Pipelines”, West Virginia University, May 2001.

[14] Bowker, C., “Corrosion of an Asbestos Cement Sewer Rising Main due to Hydrogen Sulfide”, 75th Annual Water Industry Engineers and Operators’ Conference, Bendigo Exhibition Centre, Sept 2012.

[15] Cayford, B.I., Dennis, P.G., Keller, J., Tyson, G.W., and Bond, P.L., “High-Throughput Amplicon Sequencing Reveals Distinct Communities within a Corroding Concrete Sewer System”, School of Chemistry and Molecular Biosciences, The University of Queenland, QLD, Australia.

[16] Sawyer, C.N. and McCarty, P.L., Professor of Sanitary Chemistry, MIT, and Professor of Sanitary Engineering, Stanford University, “Chemistry for Sanitary Engineers”, McGraw-Hill Book Co., Chapter 30.

[17] Stamm, W. and Morgan, J.J., Professor of Applied Chemistry, Harvard University and Professor of Environmental Enigneering, California Institute of Technology, respectively, “Aquatic Chemistry”, Wiley-Interscience.