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Detection, Control, And Correction Of Hydrogen Sulfide Corrosion In Existing Wastewater Systems

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DETECTION, CONTROL, AND CORRECTION OF HYDROGEN SULFIDE CORROSION IN EXISTING WASTEWATER SYSTEMS

September, 1992

NOTICE

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1. INTRODUCTION

1.1 Significance of Hydrogen Sulfide Corrosion in Wastewater Systems

Hydrogen sulfide corrosion is a well known and documented problem in wastewater collection and treatment systems throughout the world. The presence of hydrogen sulfide can lead to rapid and extensive damage to concrete and metal sewer pipe and tanks, mechanical equipment used in the transport and treatment of wastewater, and electrical control and instrumentation systems. Unfortunately, such problems are rarely brought to the attention of the municipality until a catastrophic failure occurs such as street collapses or sewer blockages resulting from sewer pipe failure, or complete deterioration of structural and mechanical components at wastewater treatment facilities. Wastewater systems suffering from hydrogen sulfide corrosion often require costly, premature replacement or rehabilitation of pipes, manholes, tanks, pump stations and other mechanical equipment. Electrical components, instrumentation systems, and ventilation units are particularly vulnerable to attack by hydrogen sulfide.

1.2 Purpose of Handbook

This handbook provides a comprehensive guide to detecting and monitoring corrosion, controlling corrosion rate, and rehabilitating pipes or structures damaged by corrosion. The handbook is intended for use by municipalities as well as engineers faced with existing or potential corrosion problems. Techniques are presented to allow determination of whether a corrosion problem exists, and the severity of the problem.

Subsequent chapters of this handbook are organized as follows:

Chapter 2:	Process of Hydrogen Sulfide Corrosion
Chapter 3:	Major Hydrogen Sulfide Corrosion Target Areas
Chapter 4:	Detection and Measurement of Hydrogen Sulfide Corrosion

Chapter 5: Alternatives for Controlling Hydrogen Sulfide Corrosion in Sewers
Chapter 6: Alternatives for Controlling Hydrogen Sulfide Corrosion at Pump Stations and Treatment Facilities
Chapter 7: Rehabilitation of Corroded Sewers

Case studies are included as Appendix A.

2.0 PROCESS OF HYDROGEN SULFIDE CORROSION

2.1 Basic Mechanism of Hydrogen Sulfide Corrosion

2.1.1 Sulfuric Acid Corrosion

Hydrogen sulfide corrosion occurs in sewers, tanks, and equipment conveying or treating wastewater that contains dissolved sulfide. The biological activity of anaerobic bacteria results in the formation of sulfide which is released to the surrounding atmosphere as hydrogen sulfide gas. In the presence of moisture, the hydrogen sulfide gas is biologically converted to sulfuric acid. The sulfuric acid attacks exposed concrete and unprotected surfaces of iron, steel and copper, resulting in corrosion and deterioration of the exposed vulnerable materials. The process of sulfide generation and sulfuric acid corrosion is as follows(1):

- In aquatic environments lacking dissolved oxygen, strict anaerobic bacteria colonize the slime layer that coats the submerged surfaces of pipes and tanks. These bacteria reduce sulfate (SO_4^{2-}), one of the most common anions in water and wastewater, to sulfide (S^{2-}).

- The sulfide ion combines with hydrogen ions in the wastewater to form hydrogen sulfide. Depending on pH, the hydrogen sulfide dissociates to dissolved hydrogen sulfide gas (H_2S), hydrosulfide ion (HS^-), and sulfide ion (S^{2-}). At neutral pH of 7, the distribution is approximately 50 percent H_2S and 50 percent HS^-. At pH 6, the distribution is approximately 90 percent dissolved hydrogen sulfide gas and 10 percent hydrosulfide ion.

- Dissolved hydrogen sulfide gas is the only form of dissolved sulfide which can be released from the wastewater to the atmosphere. The H_2S produces the "rotten egg" odor characteristics of stagnating sewage. The release of H_2S from solution is accelerated under turbulent conditions. Since equilibrium conditions are rarely observed, it is often difficult to predict atmospheric H_2S concentration based on the quantity of sulfide in solution.

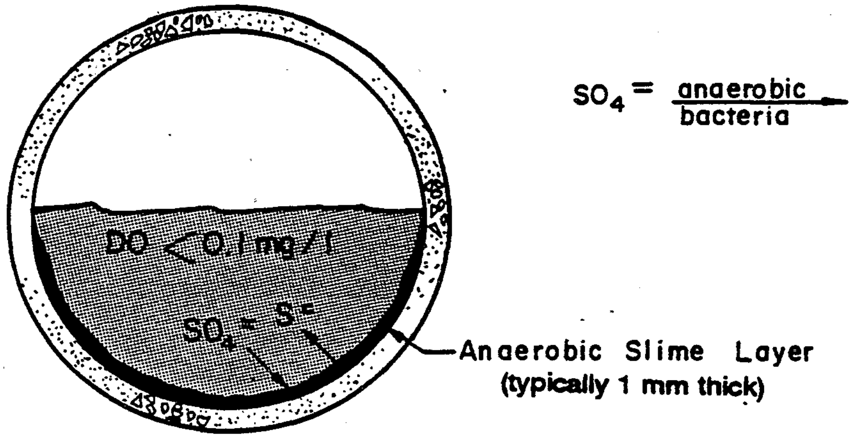
- The released H_2S combines with moisture on the non-submerged surfaces of pipe, tanks and other non-submerged surfaces and is biologically oxidized to sulfuric acid. Progressively acid-tolerant species of aerobic bacteria will successively colonize the surfaces as additional sulfuric acid is produced and the pH drops. While new concrete has an alkaline surface pH, weathered concrete has a surface pH of about 6, and concrete which is subject to active sulfuric acid corrosion may have a surface pH of 1 to 3.

- The hydrogen ions of the acid attack the calcium hydroxide in the hydrated Portland cement of concrete sewer pipes, channels and tanks while the sulfate combines with the calcium ions to form gypsum ($CaSO_4$), a soft corrosion product. In the early stages of corrosion, the concrete swells, making it difficult to measure concrete loss due to corrosion.

Figure 2-1 summarizes the corrosion process which occurs in concrete sewers and structures (2).

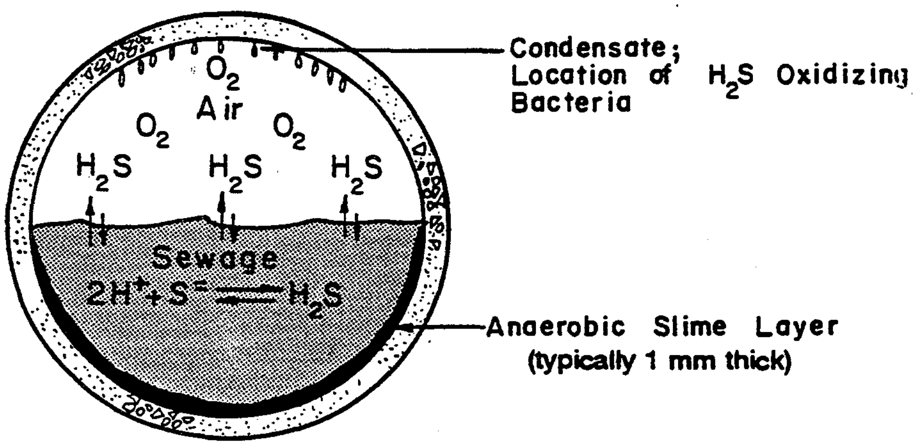
2.1.2 Direct Hydrogen Sulfide Attack of Metals

Another significant mechanism of corrosion is direct attack of metals such as iron, steel, and copper by hydrogen sulfide gas. Electrical and instrumentation systems are particularly vulnerable to low levels of hydrogen sulfide gas. H_2S readily attacks copper contacts to form copper sulfide, a poor conductor of electricity. This can cause equipment failure or poor reliability of control systems. In addition, hydrogen sulfide attack can result in substantial damage to wastewater processing equipment, steel structures and components, and iron and steel pipe.

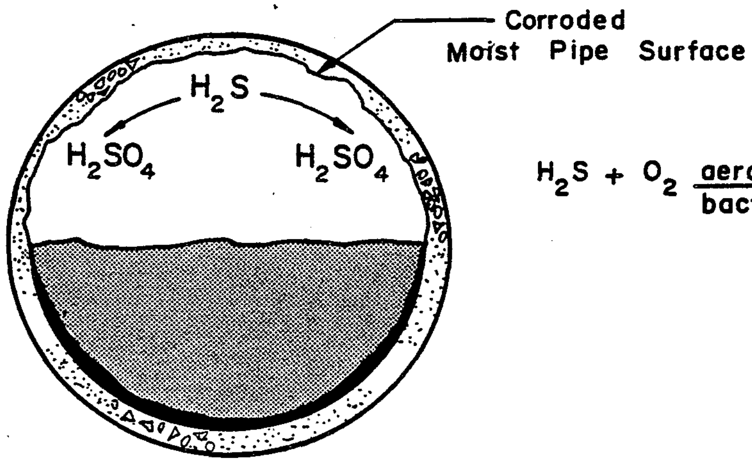


$SO_4^{=} \xrightarrow[\text{bacteria}]{\text{anaerobic}} S^{=}$

(A) Sulfate is biologically reduced to sulfide in the anaerobic slime layer on the submerged pipe wall.



(B) H_2S formed in the wastewater is released from solution as a gas and enters the sewer atmosphere.



$H_2S + O_2 \xrightarrow[\text{bacteria}]{\text{aerobic}} H_2SO_4$

(C) H_2S is oxidized to sulfuric acid by aerobic. Thiobacillus bacteria living on moist, non-submerged surfaces. Acid attacks concrete, causing corrosion.

Figure 2-1

Mechanism of Sulfide Generation and Corrosion in Sewers

2.2 Factors Affecting Corrosion

The rate of hydrogen sulfide corrosion is affected by the characteristics of the wastewater, the collection system, the type of unit processes used in the transport and treatment of wastewater, and materials of construction. Many variables directly or indirectly affect sulfide generation, H_2S release, and sulfuric acid corrosion. The factors that affect corrosion are indicated in Table 2-1. Odor and corrosion problems associated with the collection, handling and treatment of domestic wastewater is primarily due to the result of the reduction of sulfate to H_2S under anaerobic conditions, as shown by the following equation (1):

$$SO_4^{2-} + \text{organic matter} \xrightarrow[\text{bacteria}]{\text{anaerobic}} S^{2-} + H_2O + CO_2$$

$$S^{2-} + 2\,H^+ \longrightarrow H_2S.$$

Biological activity within wastewater results in the formation of a slime layer on the submerged walls of pipes or tanks. The slime layer need only be a few cell diameters thick to support bacterial colonization. That portion of the slime layer furthest from the liquid becomes increasingly devoid of dissolved oxygen. Within a dissolved oxygen range of 0.1 to 0.5 mg/l, anaerobic bacteria utilize sulfate and organic matter present in the wastewater at an approximate ratio of 2 to 1, respectively, to form sulfide. The thickness of the slime layer is controlled by velocity, which in turn is governed by pipe diameter, flowrate, and energy gradient. The proliferation of sulfate-reducing bacteria is dependent on dissolved oxygen concentration, temperature, humidity, sulfate content and availability of organic matter. The formation and release of hydrogen sulfide gas to the atmosphere is dependent primarily upon the pH of the wastewater and the degree of turbulence.

For sewer systems having low velocities, pump station wet wells, treatment tanks and other quiescent wastewater environments, deposition of organic solids may occur, promoting anaerobic conditions. Also, as the depth of flow in sewers increases, so does the surface

TABLE 2-1

FACTORS AFFECTING SULFIDE GENERATION AND CORROSION IN SEWERS(2)

FACTOR	EFFECT
Wastewater Characteristics	
Dissolved oxygen	Low DO favors proliferation of anaerobic bacteria and subsequent sulfide generation
Biochemical oxygen demand (organic strength)	High BOD encourages microbial growth and DO depletion, and increases sulfide generation in proportion to BOD concentration
Temperature	High temperature increases microbial growth rate and lowers DO solubility
pH	Low pH favors shift to dissolved H_2S gas
Presence of sulfur compounds	Sulfur compounds required for sulfide generation
Humidity of sewer atmosphere	Biological growth requires high humidity level
Sewer System Characteristics	
Slope and velocity	Affects degree of reaeration, solids deposition, H_2S release
Turbulence	Same effect as slope/velocity
Intermittent surcharging	Reduces oxygen transfer and promotes sulfide generation. May inhibit acid production by flushing and dilution.
Force main discharges	H_2S generated under anaerobic conditions in the force main is released from solution at the discharge.
Sewer pipe materials	Corrosion resistance of pipe materials varies widely
Concrete alkalinity	Higher alkalinity reduces corrosion rate
Accumulated grit and debris	Slows wastewater flow, traps organic solids and increases sulfide generation

area available for the development of a slime layer below the water surface. As the detention time increases, oxygen consumption also increases, organic matter becomes increasingly solubilized and the oxidation-reduction potential (ORP) decreases. These conditions favor the sulfate-reducing organisms.

The presence of dissolved oxygen in the wastewater stream encourages growth of an aerobic portion of the slime layer. In such cases sulfide produced in the anaerobic portion of the slime layer is likely to be oxidized in the aerobic zone.

Temperature also has a significant impact on the biological activity of the sulfate reducing bacteria. It has been reported that the rate of sulfide production is increased seven percent for every Celsius degree increase up to 40°C (4). This is equivalent to doubling the reaction rate for every 10°C increase in temperature.

Atmospheric hydrogen sulfide gas concentrations appear to be proportional to the rate of sewer corrosion that occurs. The proportionality may not be linear, however, as there may be a limiting hydrogen sulfide level above which the oxidation reaction rate does not increase. At that point, sulfur is stored as yellow deposits (3).

Finally, pH of the sewage governs the ratio of H_2S gas and HS^- ions in solution. This is important in determining the potential for H_2S gas release into the atmosphere, and, consequently, the potential for the formation of sulfuric acid and corrosion. The CSDLAC study also found the pH of the concrete surface to increase as relative humidity of the sewer atmosphere dropped below 80 - 90 percent indicating that thiobacilli need moisture to biologically convert hydrogen sulfide to sulfuric acid.

The CSDLAC study found that even when sewage contains oxygen, and dissolved sulfide levels are less than 0.1 mg/l, there still remains a significant concentration of hydrogen sulfide in a sewer atmosphere. As a result, concrete corrosion can be expected to continue even when dissolved sulfide levels are quite low (3).

2.3 Effects of Industrial Pretreatment

Another factor which may affect the rate of corrosion is the concentration of metals and other wastewater constituents resulting from industrial discharges. Studies conducted by the County Sanitation Districts of Los Angeles County (CSDLAC) have demonstrated that the reduction in metals and other industrial constituents has apparently caused an acceleration in corrosion rate, possibly due to biological inhibition of sulfate-reducing bacteria and/or chemical precipitation by iron and other metals (2)(3). The compounds which showed the highest correlation between reduction in concentration and an increase in dissolved sulfide included nickel, chromium, zinc, cadmium, copper, cyanide, lead, and iron (5). The CSDLAC study also noted that detergent manufacturers have made changes over the past 20 years in the sulfonated compounds which occur in surfactant and brightener formulations. These changes may allow for easier biodegradation of the sulfur compounds. This same study cites a 1,000% increase in dissolved sulfide when comparing 1987 to 1971-1974 data. However, site visits conducted by EPA to compare corrosion in residential versus industrial sewers were inconclusive regarding the impacts of metals and other industrial constituents on hydrogen sulfide corrosion. No wastewater systems other than CSDLAC have been found to have sufficient historical data to establish a relationship between industrial pretreatment and hydrogen sulfide corrosion.

It should be noted that there are several aspects of industrial pretreatment that can lead to reduced sulfide generation. A reduction in certain industrial discharges can directly impact sulfide generation and corrosion. These are listed in Table 2-2.

TABLE 2-2

BENEFICIAL IMPACTS OF CONTROLLING INDUSTRIAL DISCHARGES ON HYDROGEN SULFIDE CORROSION

Type of Discharge Controlled	Benefit
Sulfide-bearing wastes	Lowers sulfide levels, corrosion potential
High organic strength wastes	Sulfide generation rate proportional to organic strength; reduction in organic strength reduces oxygen uptake and depression of dissolved oxygen in wastewater
High temperature wastes	Lower temperature reduces sulfide generation rate; increases solubility of H_2S, reducing release of H_2S; increases solubility of oxygen
Wastes containing fats, oils, and grease	Reduces potential for sewer clogging, reduced velocities, solids deposition, and sulfide generation
Acidic wastes	Maintaining pH at or above neutral decreases amount of H_2S available for release to the sewer atmosphere

2.4 References

1. Bowker, R.P.G., J.M. Smith, and N.A. Webster, Odor and Corrosion Control in Sanitary Sewage Systems and Treatment Plants, Design Manual, U.S. Environmental Protection Agency, Center for Environmental Research, Cincinnati, OH, 1985.

2. Sulfide Corrosion in Wastewater Collection and Treatment Systems, Report to Congress, U.S. Environmental Protection Agency, Office of Water, Washington, DC, 1991.

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4. Pomeroy, R., F.D. Bowlus, "Progress Report on Sulfide Control Research," Sewage Works Journal 18 (4), pp. 597-640, 1946.

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3. MAJOR HYDROGEN SULFIDE CORROSION TARGET AREAS

Hydrogen sulfide corrosion can damage pipes, structures, and equipment used in the collection and treatment of wastewater. The degree of corrosion that results is impacted by the design and construction of the facilities, existing loading conditions, and operation and maintenance practices. Certain unit processes are more susceptible to corrosion damage than others, generally due to the condition of the wastewater or sludge and the characteristics of the process. For example, even if wastewater entering a treatment facility is aerobic and devoid of hydrogen sulfide, sulfide generation can occur in a primary clarifier due to the quiescent conditions and long detention times. The H_2S gas can be readily released from solution at the turbulent effluent weirs. Hydrogen sulfide which is generated in primary clarifiers, sludge thickeners, and sludge holding tanks is typically released in significant quantities during sludge dewatering operations.

Turbulence is a major factor in the generation and release of H_2S from solution. In cases where dissolved sulfide is not present, turbulence can be beneficial in promoting the transfer of oxygen into solution, maintaining aerobic conditions. However, if dissolved sulfide is present in concentrations as low as 0.1 to 0.2 mg/l, turbulence can dramatically increase the rate at which the dissolved hydrogen gas is released to the atmosphere to cause potential corrosion problems.

This chapter describes the various components of a wastewater collection and treatment system which are most likely to result in generation and release of hydrogen sulfide gas. Upon release from solution, the hydrogen sulfide can cause odor and/or corrosion problems.

3.1 Gravity Sewers

Gravity sewers form an integral part of the entire wastewater collection infrastructure and, as such, are generally designed to accommodate growth well into the future (50 years is not an uncommon design practice). Often, sewer designers will utilize larger pipe at shallower slopes to minimize the sewer depth and construction cost. Both of these practices often result in lower wastewater velocities during the initial years when the sewer carries substantially lesser volumes.

Wastewater velocity directly impacts wastewater detention time within the sewer, the amount of grit and organic solids deposition (both of which tend to further reduce wastewater velocity and increase depth of flow), and the extent of slime layer buildup within the submerged portion of the sewer. Velocity thus affects formation of dissolved sulfide and also the release of hydrogen sulfide gas into the sewer atmosphere. The hydrogen sulfide gas is biologically converted to sulfuric acid in the presence of moisture and oxygen and attacks cementitious materials such as concrete pipe and mortar. In addition, hydrogen sulfide gas and sulfuric acid directly attack ferrous metal and copper surfaces. The most vulnerable pipe areas prone to sulfide corrosion are the crown of the pipe and wall areas normally above the wastewater level. If allowed to continue over a long period of time, the hydrogen sulfide corrosion can eventually lead to pipe failure and trench collapse.

Other gravity sewer components affected by sulfide corrosion are sewer manholes, junction chambers, metering vaults, and other structures. Manholes often serve as junctions for two or more sewers. Typically, the smaller sidestream sewer will enter the manhole at an elevation higher than the mainline sewer invert. This is to prevent surcharging of the smaller sewer during periods of sustained high flow in the larger sewer. There can also be substantial elevation differences in deep sewer situations, where, due to ground surface topography, the sidestream sewer does not need to be installed as deeply as the mainline sewer. These vertical drops can cause significant turbulence. A drop connection installed upstream of the connecting manhole will help minimize hydrogen sulfide release. Also, unless manhole inverts are properly formed to promote smooth hydraulic conditions, excessive turbulence can occur due to abrupt changes in horizontal or vertical alignment.

While turbulence allows introduction of air (oxygen) into the wastewater, it also causes the release of hydrogen sulfide gas. The hydrogen sulfide corrosion process can then deteriorate manhole walls, ladder rungs and any other corrosion-prone material. Some manholes are being provided with corrosion-resistant ladder rungs rather than iron and steel used in past decades, but the inserts can potentially become structurally deficient if the surrounding concrete is allowed to corrode.

3.2 Pump Stations and Force Mains

Pump station wet wells can contribute to sulfide corrosion problems by promoting the generation of sulfide within the wet well itself. Further, hydrogen sulfide gas from the upstream sewer atmosphere may enter the wet well. Excessive turbulence in the wet well caused by vertical drops from the influent pipe to the wastewater surface causes release of hydrogen sulfide gas from the solution. This release of hydrogen sulfide gas to the atmosphere likely will lead to odor complaints in populated areas.

Influent sewers at wastewater treatment plants may become surcharged if inlet screens or comminutors are present but not properly maintained. Sewers discharging to a pump station may also be surcharged if the wet well level is allowed to rise above the influent sewer.

As with sewers, pump station wet wells are normally designed for future flows. While this practice makes economic sense, it does allow for excessive detention times during the initial years of operation. The longer the detention time, the greater the likelihood that organic matter will settle to the wet well bottom, and the wastewater will become septic. Unless the pump suction pipes and wet well geometry are appropriately designed, the accumulation of organic matter will aggravate the generation of dissolved sulfide and hydrogen sulfide gas. Options to consider in reducing the long detention times in wet wells include utilizing a smaller portion of the wet well, adjusting the "pump-on" and "pump-off" levels, or using variable speed pumps. Wet well cleaning should be performed on a routine basis.

Wet well corrosion can include the concrete or masonry structure, access covers, ladders and stairs, bar racks and comminutors, control devices such as sluice gates, slide gates and weirs, heating and ventilating systems, and electrical components. Electrical contacts are particularly susceptible to corrosion failure.

Force mains, inverted siphons and other surcharged pipes are normally completely full of wastewater, and because this condition does not allow reaeration from the sewer atmosphere, dissolved oxygen levels in the wastewater become depleted, and significant quantities of dissolved sulfide can be generated. Since the pipes are generally full of wastewater, corrosion will not occur within surcharged pipes unless they contain an air pocket. If an air pocket exists, corrosion may occur very quickly. This situation has been reported at several locations throughout the U.S.. Upon reentry to a gravity sewer or treatment plant headworks, an immediate release of hydrogen sulfide gas occurs due to the high level of turbulence. Force main and inverted siphon terminus locations are therefore highly susceptible to hydrogen sulfide corrosion and should be routinely monitored. Other areas of concern with regard to hydrogen sulfide corrosion include special structures such as those utilized for flow measurement, and valves used for flow isolation and air release.

3.3 Treatment Facilities

Corrosion damage can be extensive at the headworks of wastewater treatment facilities, particularly if long influent force mains or large diameter gravity sewers constructed at flat slopes discharge to the facility. These influent sources typically convey wastewater which is septic and already has a significant dissolved sulfide concentration. Headworks areas most susceptible to corrosion attack include influent channels, flow measurement facilities, comminutors and bar racks, grit chambers and areas where vertical drops occur. All of these components promote turbulent conditions and the resultant release of hydrogen sulfide gas. In addition, septage or other high-strength wastewater and sidestream returns may contribute to the generation and release of hydrogen sulfide. All components used in headworks areas should be inspected regularly due to the high potential for hydrogen sulfide corrosion.

Septic conditions are likely to occur in primary clarifiers due to the quiescent conditions and long detention times. The most critical areas with regard to the release of hydrogen sulfide are launders, troughs, effluent weirs and outlet channels, especially where large drops in elevation occur. Because these components are normally open to the atmosphere, the corrosion potential is lessened somewhat, though the odor potential remains very high.

Secondary biological treatment processes are not normally considered to be sources of sulfide generation due to the presence of aerobic conditions. Localized problems can develop, however, in areas having either poor wastewater distribution or poor air distribution, which results in anaerobic zones. Also, trickling filters which are heavily loaded can generate sulfide. Secondary clarifiers and subsequent downstream facilities normally are not areas of hydrogen sulfide corrosion due to the aerobic conditions and high wastewater quality at these stages. Enclosed secondary clarifiers should be monitored, however, due to the minimal ventilation provided. Catwalks, railings and other structural elements and fasteners should be constructed of corrosion-resistant materials.

Sludge storage tanks, sludge thickeners, sludge dewatering systems, and solids processing operations in general are particularly susceptible to hydrogen sulfide corrosion. This is due to the rapid generation of hydrogen sulfide in sludge storage tanks and gravity thickeners. Introduction of turbulence, such as from dewatering equipment, can substantially increase H_2S release and corrosion potential.

Within any enclosed space containing H_2S, most concrete and metallic surfaces are susceptible to corrosion, particularly in poorly ventilated areas. Structural elements such as gratings, railings, platforms, structural inserts, clamps and beams are prone to hydrogen sulfide attack, either directly by chemical reaction, or by acid attack. In addition, electrical components are particularly sensitive to hydrogen sulfide corrosion, because copper, iron and silver are all directly attacked by hydrogen sulfide gas. Other affected processes include heating and ventilating systems and wastewater processing equipment.

Appendix A includes case studies describing hydrogen sulfide corrosion problems at wastewater collection and treatment facilities.

3.4 References

1. Sulfide in Wastewater Collection and Treatment Systems, ASCE Manual of Practice - No. 69, American Society of Civil Engineers, 1989.

2. Bowker, R.P.G., J.M. Smith, and N.A. Webster, Odor and Corrosion Control in Sanitary Sewage Systems and Treatment Plants, Design Manual, U.S. Environmental Protection Agency, Center for Environmental Research, Cincinnati, OH, 1985.

3. Hydrogen Sulfide Corrosion in Wastewater Collection and Treatment Systems, Technical Report, U.S. Environmental Protection Agency, Office of Water, Washington, DC, 1990.

4. DETECTION AND MEASUREMENT OF HYDROGEN SULFIDE CORROSION

4.1 Approach for Identifying Existing or Potential Corrosion Problems

Figure 4-1 shows a flow diagram of the basic steps involved in identifying existing or potential corrosion problems. These steps are:

1. Reviewing existing information to identify potential problem areas.
2. Conducting preliminary inspection of potential problem areas.
3. Conducting detailed inspections and measuring corrosion at known problem areas.
4. Estimating corrosion rates and prioritizing areas for further monitoring and/or correction.

These four steps are discussed in subsequent sections of this chapter.

4.2 Identifying Potential Problem Areas

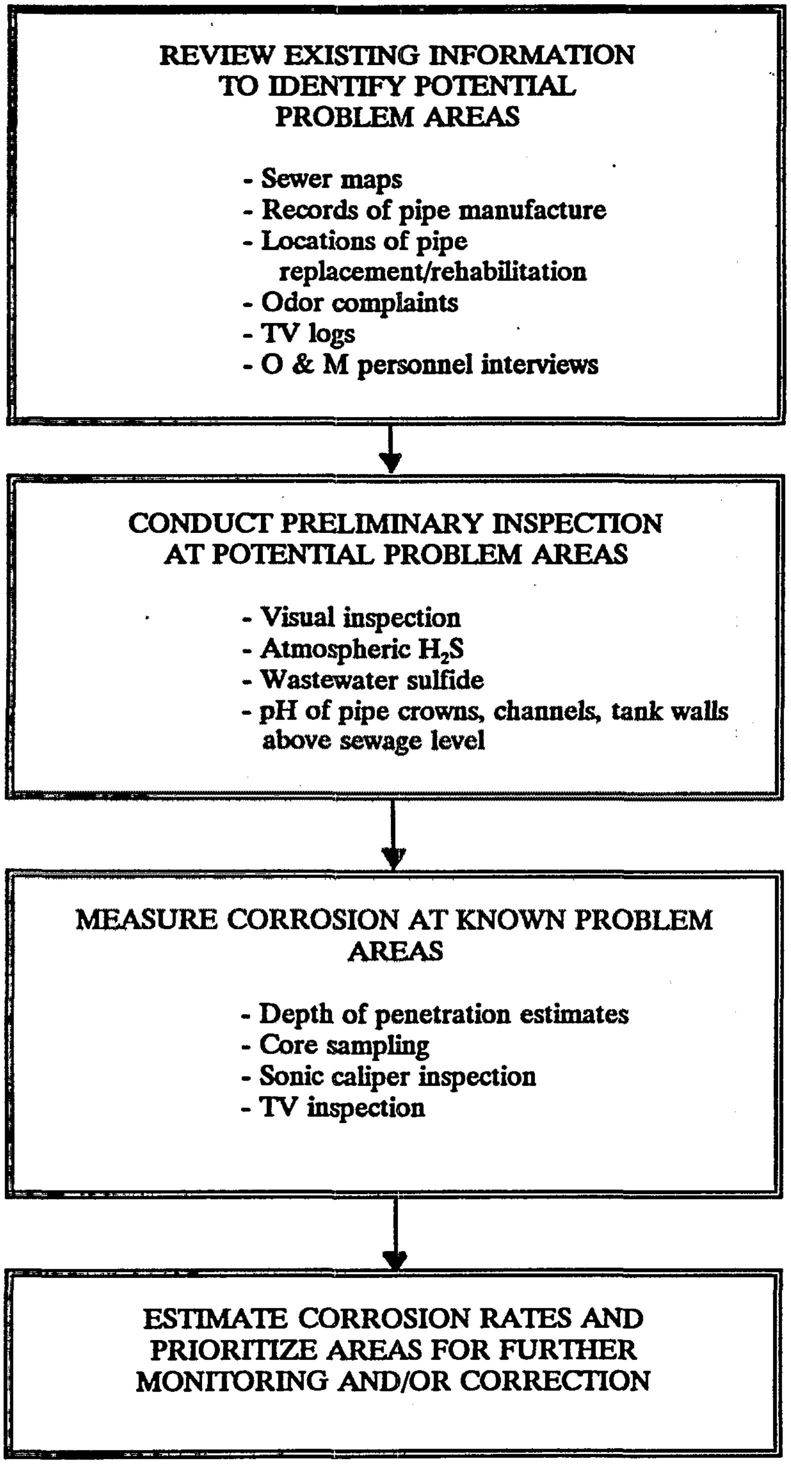
A review of the layout and design of the existing collection and treatment system and other information is useful to identify areas that are susceptible to corrosion problems. These areas should be highlighted on sewer maps and other available plans for subsequent inspections in the field.

Areas where septic wastewater conditions are likely to develop are also areas with corrosion potential. Force mains are a major source of sulfide generation. Where force mains discharge into gravity sewers, wet wells, or junction chambers, substantial quantities of H_2S can be released due to turbulent conditions, creating conditions ripe for corrosion. Force main discharges and inverted sewer ("siphon") outlets should receive priority for inspection.

Gravity sewers with low velocities or long detention times should also be identified as

FIGURE 4-1

APPROACH TO IDENTIFYING EXISTING AND POTENTIAL CORROSION PROBLEMS



REVIEW EXISTING INFORMATION TO IDENTIFY POTENTIAL PROBLEM AREAS

- Sewer maps
- Records of pipe manufacture
- Locations of pipe replacement/rehabilitation
- Odor complaints
- TV logs
- O & M personnel interviews

CONDUCT PRELIMINARY INSPECTION AT POTENTIAL PROBLEM AREAS

- Visual inspection
- Atmospheric H_2S
- Wastewater sulfide
- pH of pipe crowns, channels, tank walls above sewage level

MEASURE CORROSION AT KNOWN PROBLEM AREAS

- Depth of penetration estimates
- Core sampling
- Sonic caliper inspection
- TV inspection

ESTIMATE CORROSION RATES AND PRIORITIZE AREAS FOR FURTHER MONITORING AND/OR CORRECTION potential problem areas due to the possibility of sulfide generation. Problems often occur in pipes sized for future development that has not yet occurred. Pipes installed at flat slopes with low sewage velocities are subject to potential corrosion problems.

Pumping stations should be earmarked for inspection, since hydrogen sulfide is often generated in wet wells. Septic wastewater entering metering stations, junction chambers, drop manholes, and wet wells may be subjected to sufficient turbulence to release H_2S that has formed upstream. In general, any areas of high turbulence in the collection system should be targeted for inspection.

Locations where odor complaints have originated should be identified on the map. Odor complaints often result from hydrogen sulfide gas escaping from manholes or vents. Hydrogen sulfide gas is responsible for the "rotten egg" odor associated with septic sewage.

Records of pipe manufacturers should be reviewed. For instance, the corrosion rate of spun concrete pipe can be as little as one-third of that found in cast concrete pipe, given the same H_2S level and acid production rate. This phenomenon occurs due to the presence of an alkali-rich layer on the spun pipe. Once this layer is lost to corrosion, however, the corrosion rate increases. Slower initial rates of corrosion can be similarly expected with concrete pipe containing calcarious aggregate or sacrificial layer. Without information pertaining to pipe manufacture, it is extremely difficult to predict corrosion rates. Alternatively, if no records exist, core samples can be taken to determine the materials of construction.

Sewer maintenance staff should be consulted to help identify potential trouble spots in the system. Such discussions can be very valuable. Records of sewer and treatment facility rehabilitation or replacement should be reviewed to determine if corrosion was a factor in requiring rehabilitation work. If TV tapes and/or logs are available for a portion or all of the system, these should be reviewed to determine if corrosion was noted. Poor resolution with early generation TV systems may make identification of corrosion difficult, especially to the untrained observer.

Corrosion at the headworks of the wastewater treatment plant may be indicative of upstream corrosion problems. Bar screens, concrete channels, grit chambers and electrical equipment at the headworks should be identified for subsequent inspection. Primary clarifiers, sludge handling systems and other unit processes discussed in Chapter 3 should also be evaluated.

Figure 4-2 shows a typical sewer map with potential corrosion problem areas targeted for inspection.

4.3 Preliminary Inspection

A preliminary inspection of areas having the potential for corrosion problems can determine 1) the presence or absence of corrosion, 2) the extent of the problem, and 3) the severity of the problem. The inspection will also indicate the need for further inspections and/or corrective actions, and may lead to a regular program of inspection and monitoring. Because the preliminary inspection involves measurement of certain parameters that are affected by wastewater temperature, it is recommended that the inspection be conducted during summer months when hydrogen sulfide is most likely to be present.

The preliminary inspection generally involves the following elements:

- Measurement of atmospheric H_2S
- Visual inspection
- Measurement of temperature and pH in wastewater
- Measurement of total and dissolved sulfide in wastewater
- Measurement of crown pH

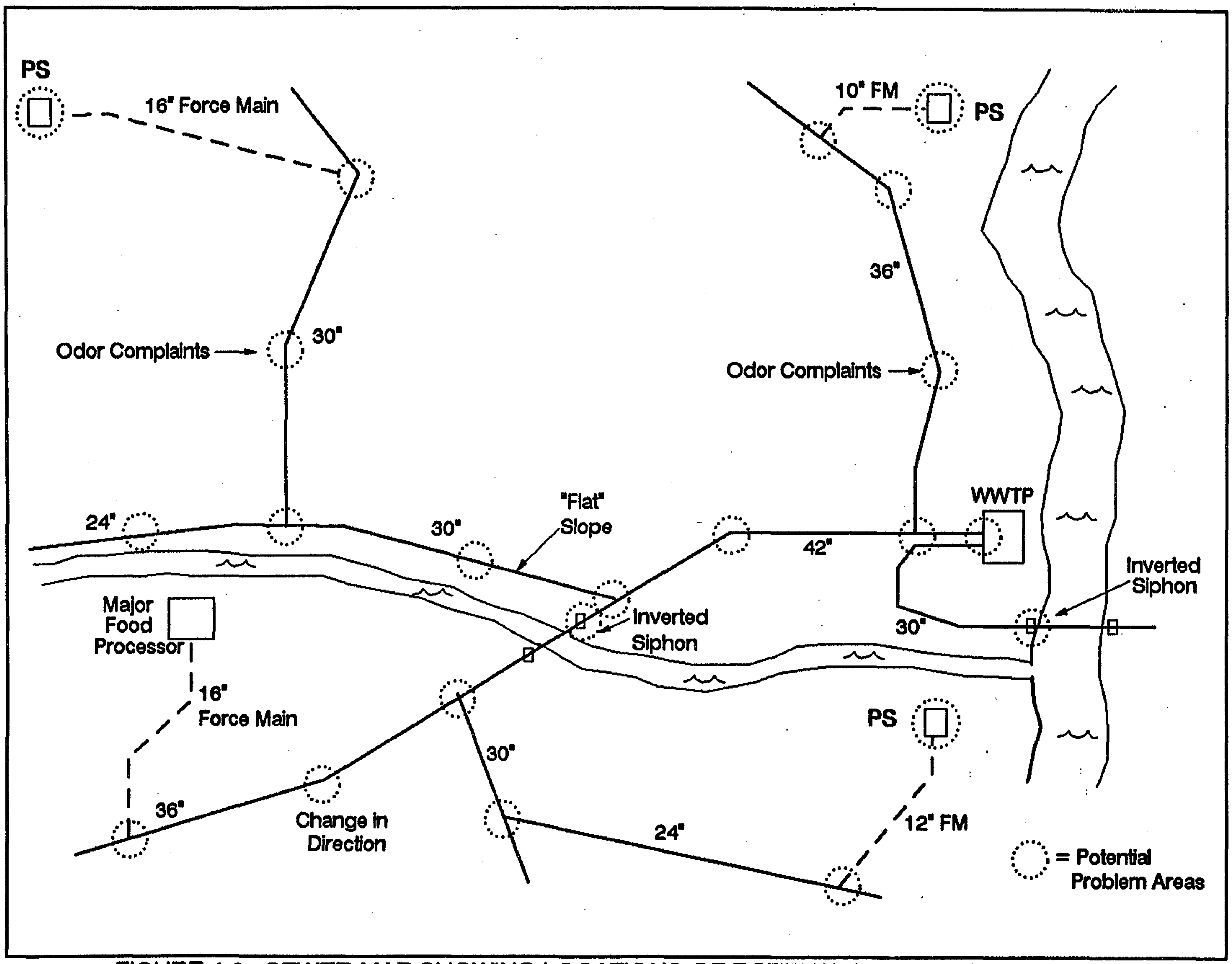


FIGURE 4-2. SEWER MAP SHOWING LOCATIONS OF POTENTIAL CORROSION PROBLEMS

A preliminary inspection checklist is shown in Figure 4-3. Each of the major elements of the inspection are described below.

4.3.1 Atmospheric H_2S

An electrochemical H_2S analyzer or simple detector tubes can be used to detect and measure hydrogen sulfide gas in the atmosphere of manholes, junction chambers, metering stations, headworks structures, etc. This technique can and should be used without entering the structure. (Measurement of H_2S, lower explosive limit, and percent oxygen is standard procedure before entering a confined space).

With electrochemical sensors, internal or external sampling pumps in combination with an extension hose should be used to allow measurement of H_2S near the water surface, since H_2S is heavier than air. Detector tubes can use either a manual or electric pump which can be fitted with an extension hose for remote sampling. Such hoses can be lowered through the pickholes of manholes or through access hatches in junction chambers and other structures without significantly disturbing the conditions in the sewer atmosphere. Opening a manhole or structure cover completely will often destroy the ambient atmospheric conditions in the sewer gas space, thus providing inaccurate H_2S measurements.

It is critical that H_2S is measured within 6 to 12 inches of the liquid surface, and that the wastewater atmosphere not be disturbed. A simple battery-powered sensor can be fabricated to serve the purpose of locating the liquid level without removing manhole covers, as depicted in Figure 4-4.

4.3.2 Visual Inspection

A visual inspection of the condition of manholes, metering stations, wet wells, headworks, and other structures is essential to identify corrosion problems. Areas that are accessible should be viewed without entering the structure. Hazardous atmosphere can exist in

FIGURE 4-3

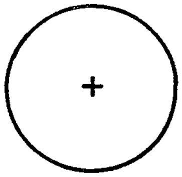
CORROSION INSPECTION CHECKLIST

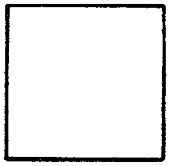
Type of Structure: Manhole____ Other______ Structure No.______

Date: ________________

Location:____

Pipe Orientation
and Sizes:


Manhole


Structure

Age of Pipe/Structure: ___________yr

Pipe Material: ___________________________

Structure Material: ___________________________

Approx. Depth of Flow: ___________________________in.

Headspace H_2S: ___________________________ppm

Sewage pH: ___________units

Temp: ___________°C/°F

Total Sulfide: ___________ mg/l

Dissolved Sulfide: ___________ mg/l

Turbulence:

_____Quiescent

_____Moderate

_____High

General conditions -

Structure:____

____

____

Pipe: ____

____

____

Evidence of corrosion -

Manhole barrel:________________

Pipe crown: ________________

Other: ________________

Bottom debris:____

____

____

Comments:____

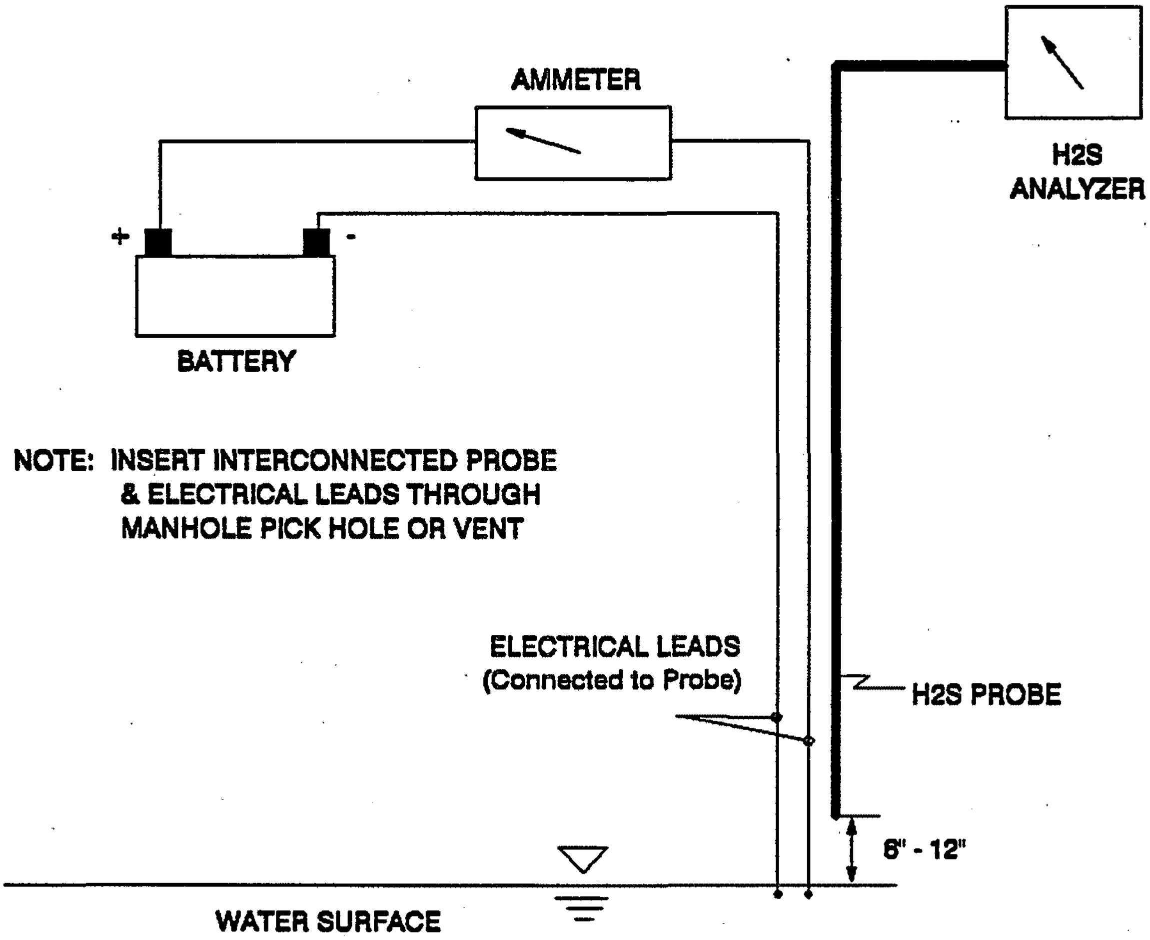
____

____

____

____

Signature



NOTE: INSERT INTERCONNECTED PROBE & ELECTRICAL LEADS THROUGH MANHOLE PICK HOLE OR VENT

FIGURE 4-4. H2S PROBE/LIQUID SENSOR DEVICE sewers, manholes and other confined spaces. Workers entering such areas must receive safety training. Proper safety procedures for confined space entry must be strictly followed (6)(7).

Items noted in a visual inspection include:

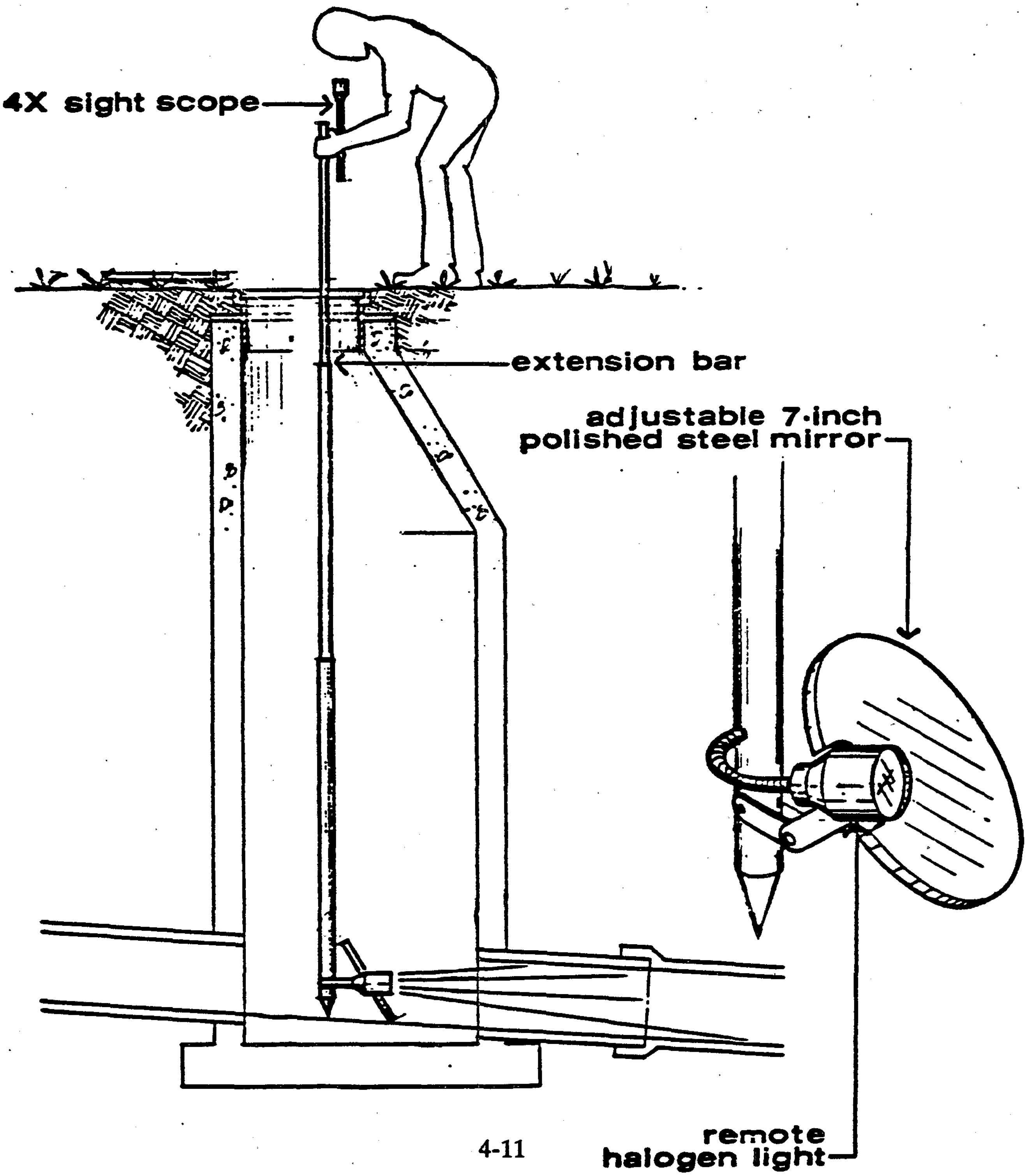
1. Condition of ladder rungs, bolts, conduit, and other metal components.
2. Presence of protruding concrete aggregate.
3. Presence of exposed reinforcing steel.
4. Development of black coating (copper sulfide) on copper pipes and electrical contacts.
5. Evidence of loss of concrete from pipe crown or walls.
6. Condition of equipment such as bar screens, grit removal systems, sludge thickening and dewatering equipment.

A quick method of inspecting the general condition of sewers can be performed with a telescoping rod onto which are attached a halogen light and adjustable mirror at one end, and a 4x sight scope at the other end, as indicated in Figure 4-5. The rod is inserted into a manhole, and by slightly tilting the rod and flashing the light beam down the sewer, its condition can be observed. This procedure is useful when small-diameter sewers are involved. Also, because entry into a confined space is not required, there is minimal risk of being overcome by potentially harmful sewer gas.

4.3.3 Measurement of Sulfide

For screening purposes, wastewater sulfide can be estimated using field test kits. Although dissolved sulfide is the best indicator of potential corrosion problems, it requires an additional flocculation and decant step prior to analysis for sulfide. For purposes of preliminary inspection, total sulfide determinations are adequate, although both total and dissolved sulfide should be determined for several samples to show the relationship between

FIGURE 4-5. QUICK METHOD OF INSPECTING SEWER LINES



the two. Dissolved sulfide normally comprises 70 to 90 percent of total sulfide.

4.3.4 Measurement of Surface pH

One of the most useful indicators in the determination of the potential for hydrogen sulfide corrosion problems is the pH of the pipe crown or structure walls and roof. A simple test using color-sensitive pH paper is applied to the moist crown wall or roof to measure the pH. New concrete has a pH of 11. After aging, the pH under non-corrosive conditions may drop to near neutral, though the presence of carbon dioxide in the sewage atmosphere can further reduce surface pH below 7. Concrete experiencing severe hydrogen sulfide corrosion may have a pH of 2 or lower. Color-sensitive pH paper is available for many ranges of pH to yield fairly accurate results. Ranges should be selected to allow accuracy to ± 0.5 pH unit. Figure 4-6 shows a simple device for obtaining surface pH without entering a confined space.

4.3.5 Measurement of Sewage Temperature and pH

Sewage temperature and pH should also be measured during the preliminary survey. pH can be measured using a laboratory pH meter, or using a simple, hand-held probe.

4.3.6 Review of Data

Data from the preliminary inspection program should be tabulated and reviewed to gain perspective on the overall magnitude of the problem. If corrosion appears severe or was identified at most sites inspected, further inspections may be justified for other areas of the collection and treatment system, and a more detailed physical measurement of the extent of corrosion should be performed.

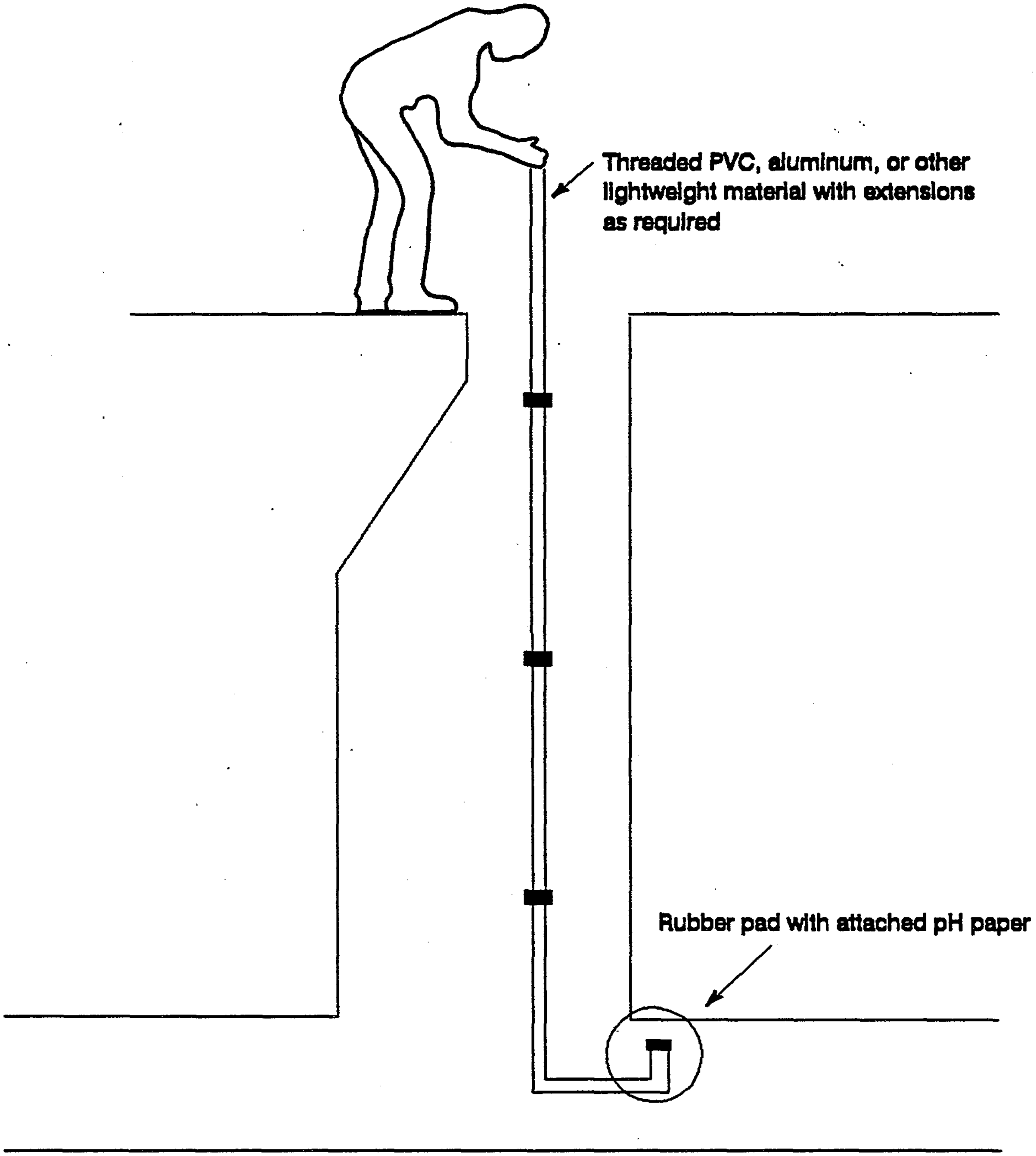


FIGURE 4-6. SEWER CROWN PH PROBE

4.4 Measurement of Corrosion

Measuring the relative extent of corrosion is useful to 1) quantify the severity of the problem, 2) estimate the rate of corrosion, 3) project the remaining useful lifetime of the structure, and 4) develop a database to calibrate predictive corrosion rate models. Measuring corrosion depth and estimating corrosion rate are often difficult and not highly accurate due to the variation in corrosion rate within a system. Consequently, data collected as part of an assessment of corrosion should be carefully reviewed, and sufficient data should be collected to allow reasonable assessments to be made.

The following are several techniques used to estimate the depth of corrosion penetration.

4.4.1 Manual Methods

The simplest but least accurate technique is to remove the soft corrosion product using a screwdriver or sharp tool until sound, uncorroded concrete is reached, and directly measure the depth of penetration. Obviously, this method has substantial limitations, since the depth is measured from a point where concrete loss has likely already occurred. Often, depth of penetration is measured from the top of protruding aggregate to exposed uncorroded concrete.

Another technique is to use extendable rods to effectively measure inside diameter of corroded pipe and compare this with the measured inside diameter of an uncorroded section. Diameters can be measured horizontally (parallel to the waterline), vertically (from crown to invert), and at various angles to yield a range of values. As with the manual technique, corrosion product must first be removed where the measurements are being taken. The problem with this approach is that pipes are likely to be slightly out-of-round, making it impossible to get accurate measurements of corrosion depth. In addition, the depth of concrete over reinforcing steel may vary within the same pipe.

Both of these techniques are most applicable to large diameter, man-entry size sewers. To estimate "average" corrosion penetration, corrosion measurements should be taken away from manholes or structures where turbulence could result in higher, localized corrosion rates. The most severe corrosion observed in gravity sewers will typically be within a distance of three to ten feet from manholes and other turbulent areas.

4.4.2 Concrete Coring

Taking a concrete core of a pipe or concrete tank wall can be useful for close examination of corrosion damage, and for estimating the depth of corrosion penetration. For measuring corrosion, coring is beneficial only if the original thickness of concrete is known. Cores can be taken from uncorroded sections or from other locations in the same structure or pipe for comparison. Cores are especially helpful when attempting to determine remaining concrete cover over reinforcing steel, which can be used to determine the remaining effective life of the pipe or structure.

Any pipe in an area with corrosion potential may be fitted with non-corroding vitrified clay plugs or stainless steel rods to establish a reference point from which future corrosion can be measured. The plugs or rods can be installed at any time, regardless of the current stage of corrosion.

4.4.3 Sonic Caliper

A recent development in remote sewer inspections is the use of "sonic caliper" technology to detect and measure the internal conditions of pipes. The sonic caliper technique uses the travel-time measurement of a sonic signal to determine the distance from the sonic transmitter to the target. The sonic caliper operates in the pulse-echo-sonar mode. Each sonic transducer acts as both a transmitter and a receiver of sonic signals. Distance measurements are made from the transducer to the walls of the pipe. The distances to the walls and the position of the transducer on a floating raft are used to calculate the vertical diameter of the pipe (1).

The sonic caliper system is comprised of an instrument raft inserted into the sewer line, a computer at the surface which controls the system and displays data, and a conductor cable which connects the two.

Figure 4-7 shows a typical sonic caliper plot. In the plot the crown loss averages two inches, and the depth of bottom debris varies from three to six inches. The actual crown loss may be somewhat greater than reported because the signals will be reflected from the first surface that they strike. This may be a corrosive crust, protruding aggregate, part of the reinforcing cage, or in some cases roots or gaskets hanging below the crown. Studying the overall trend of the longitudinal plots and also TV inspection of the line prior to sonic investigation can help to resolve any uncertainties.

In Tampa, approximately 40,000 feet of line were surveyed using this technique as part of an equipment development and demonstration project. The Tampa project yielded the following results and conclusions:

1. The equipment developed during the project was able to read dimensions in pipes from sizes 36" to 60".

2. Accuracy of the equipment was within one-half inch of the actual pipe wall thickness.

3. Completed dimension surveys were used to identify those lines in critical condition and assist in prioritizing which lines should be rehabilitated, replaced or continued in service until rescheduled for inspection.

4. The bottom transducers are useful in determining cleaning requirements for either restoration of original capacity or providing information for

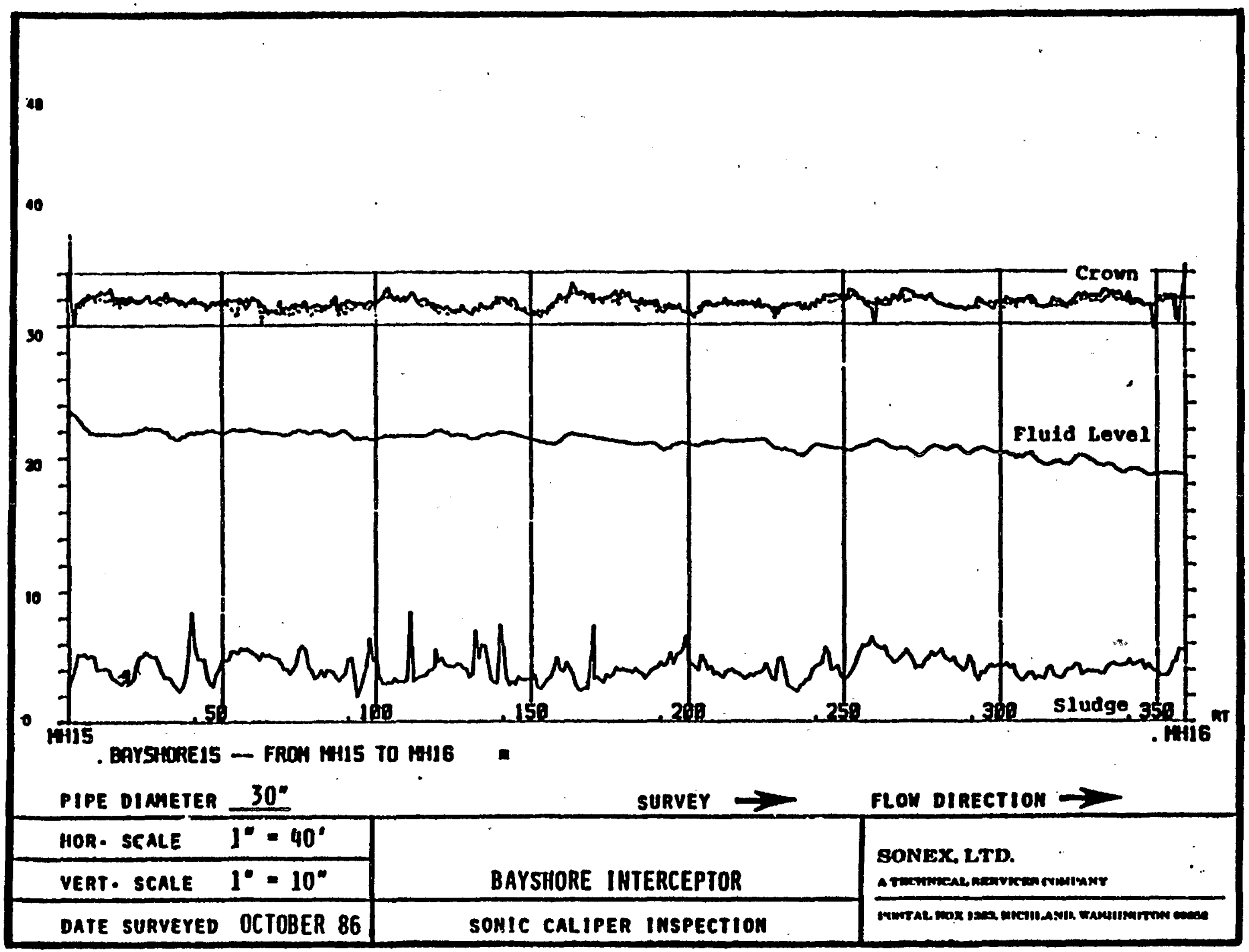


Figure 4-7. Typical sonic caliper longitudinal plot

rehabilitation by sliplining.

4.4.4 Television Inspection

Television inspection of a sewer line is not a true means of measuring corrosion. However, it can provide a relative indication of how rapidly corrosion is progressing by comparing conditions in the same line over a period of several years. It is also useful in identifying problem areas between physical access points.

TV inspection involves use of a closed-circuit television camera to observe the conditions in the sewer lines. The results are shown on a monitor, and documentation can be made by a videotape. The cameras used to inspect sewers are specially designed for sewer conditions. The camera is mounted in a casing and is pulled or pushed through the sewer with cables. Light sources are provided for illumination.

4.4.5 Other Techniques

In cases of severe corrosion and subsequent loss of portions of the pipe crown, soil and backfill may wash into the pipe, creating a void. Such conditions may eventually lead to pipe collapse.

The identification of voids can be made using infrared thermographic inspection. This thermographic system produces a temperature map displayed on a portable computer monitor. The voids show up as different colored areas on the screen, and allows the inspection crew to locate the problem areas. Concurrent with the infrared inspection, a standard visual from a video camera is recorded. This identifies any obvious deterioration (2).

The technique is useful for identifying areas where sewer collapses are likely. However, it is applicable only after substantial damage has been done to the pipe, and the subsurface void is large. For instance, work performed by the County Sanitation Districts of Los Angeles County found that upon excavation, none of the anomalies (temperature variations suggested as being possible voids) observed were related to actual sewer deficiencies. Rather, it was determined that the voids were generally within one foot of ground surface and reflected backfill density variations of little or no significance to sewer system structural integrity. The technology is, however, in its infancy and improvements may lead to a reliable means of locating sewer problems.

4.5 Comparing Measured and Predicted Corrosion

4.5.1 Introduction

The ability to identify, locate and define areas susceptible to corrosion is necessary for effective corrosion control. This ability can be enhanced through the use of predictive models. Equations have been developed to allow prediction of both sulfide generation rate and corrosion rate. Because it is imperative that reasonable assumptions be made in order to accurately predict rates of corrosion throughout a system, it is recommended that actual sulfide concentrations be obtained at all points of interest. Once this information is available, corrosion rates can be predicted. It is important to remember, however, that the predictive corrosion rates thus determined must be verified with field monitoring where possible to confirm the accuracy of the results.

4.5.2 Model for Predicting Corrosion Rate

The model for predicting corrosion rate consists of two basic equations which determine 1) the rate of flux of hydrogen sulfide to sewer walls, and 2) average and peak rates of corrosion. Based on predicted corrosion rate, a third equation predicts anticipated service life of the sewer or structure being investigated. These empirical equations are addressed in greater detail in publications by the U.S. Environmental Protection Agency, the American Society of Civil Engineers, and the American Concrete Pipe Association

(3)(4)(5).

The rate of flux of hydrogen sulfide to the sewer pipe wall can be calculated by the following equation:

$$\text{Ø}_{sw} = 0.45\,(sv)^{3/8}\,j\,[DS]\,b/p'$$

where:

Ø_{sw} = rate of flux of hydrogen sulfide to the sewer wall, in g/m^2-hr

0.45 = conversion factor from meters to feet

s = energy grade line slope of the stream

v = stream velocity, in ft/sec

j = factor relating the fraction of dissolved sulfide present as H_2S to pH (see Figure 4-8)

[DS] = dissolved sulfide concentration, in mg/l

b = surface width of stream, in feet

p' = perimeter of pipe exposed to atmosphere, in feet

Refer to Figure 4-9 for relationships of b and p' with sewers flowing partly full.

Once the rate of H_2S flux is known, the average rate of corrosion can be estimated as follows:

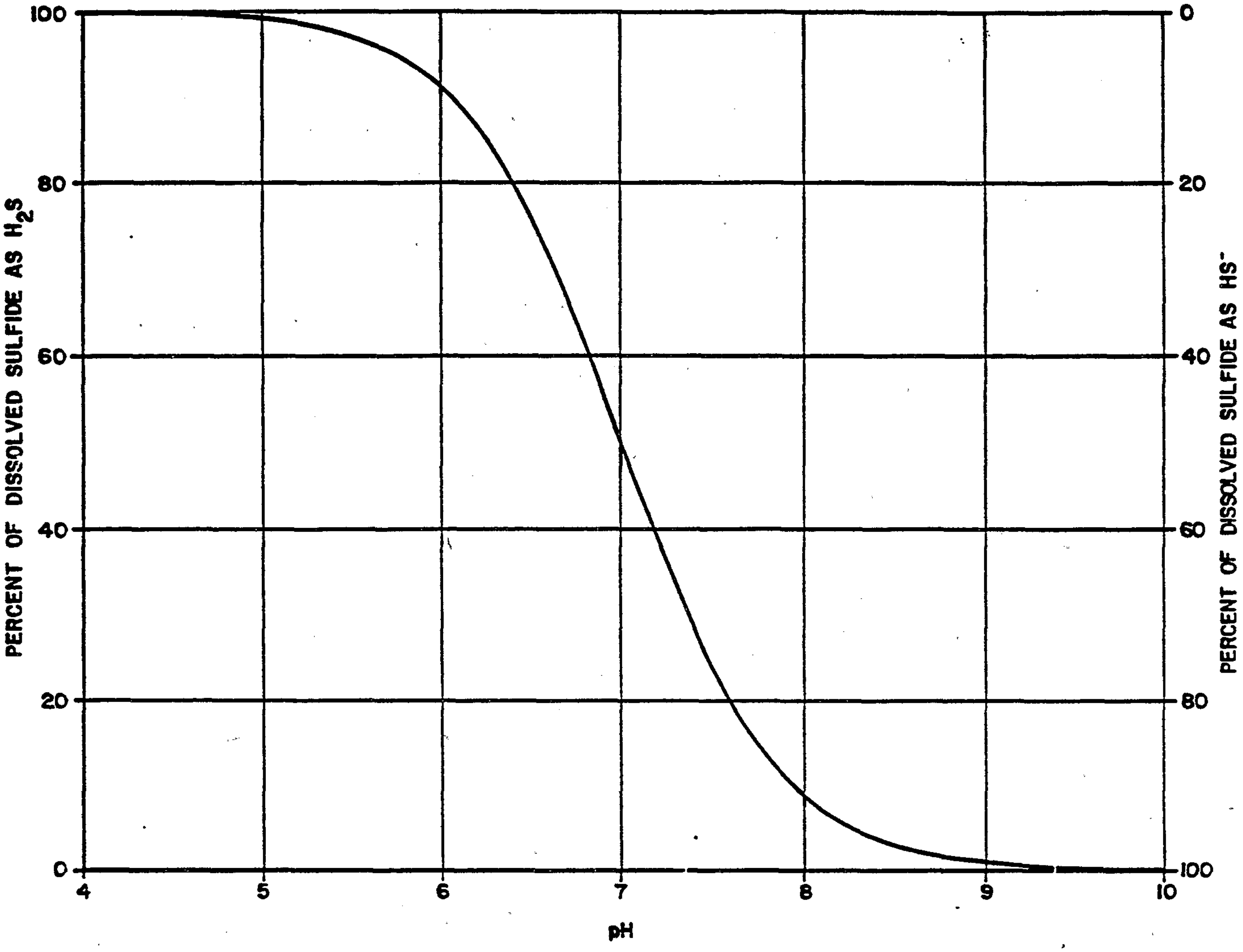
$$C_{avg} = \frac{0.45\,k\,\text{Ø}_{sw}}{A}$$

where:

C_{avg} = average corrosion rate of exposed pipe perimeter, in inches/year

0.45 = conversion factor from meters to feet

k = incomplete acid reaction factor, ranging from 0.3 to 1.0. The k factor estimates the efficiency of the acid reaction considering the estimated fraction of acid remaining on the wall. The k factor



NOTES

1. RELATIONSHIP SHOWN IS FOR AVERAGE VALUE OF $k_1 = 10^{-7}$; k_1 VARIES SOMEWHAT WITH SALINITY AND TEMPERATURE.
2. CONCENTRATION OF $S^=$ IS NEGLIGIBLE IN pH RANGE SHOWN.

Figure 4-8. Relationship of Dissolved Sulfide Equilibrium to pH

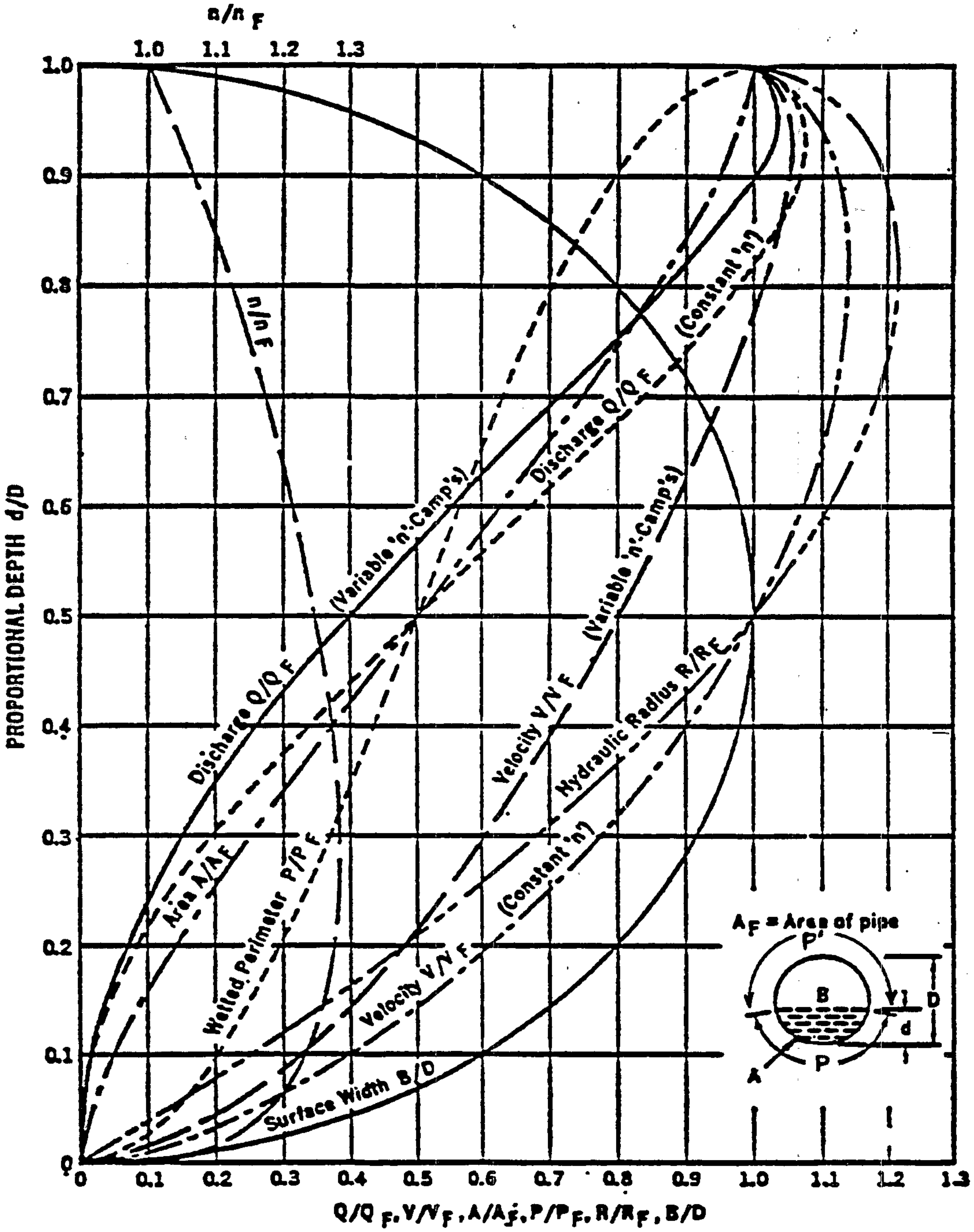


Figure 4-9. Hydraulic Elements of Circular Sewers Running Partly Full

approaches unity for complete acid reaction.

A = concrete alkalinity, expressed as calcium carbonate, equivalent decimal fraction. For granitic aggregate concrete, A is 0.17 to 2.0. For calcareous aggregate, A is 0.9 to 1.1. The A value for mortar lining is 0.4, and 0.5 for asbestos cement. For ferrous pipe, a value of 0.5 should be used to account for direct attack by H_2S (4).

It must be stressed that the value obtained in the above-noted equation results in an average value for the corrosion rate. Studies indicate that peak corrosion rates up to 1.5 to 2.0 times the average rate may occur at the sewer crown. High turbulence levels increase the release of H_2S and subsequent corrosion rate. The "crown corrosion factor" and "turbulence corrosion factor" are used to account for these conditions. The peak rate is determined by the following equation:

$$C_{max} = C_{avg} \times CCF \times TCF$$

where:

C_{max} = Maximum rate of corrosion, in inches/year

C_{avg} = Average rate of corrosion, as previously determined

CCF = Crown corrosion factor, ranging from 1.5 to 2.0

TCF = Turbulence corrosion factor, which typically varies from 1.0 to 2.5 for well-designed junction structures or other areas with nonuniform flow conditions, to 5.0 to 10.0 for drops and other turbulent junctions.

Finally, the useful life expectancy of the sewer can be approximated by the equation:

$$L = \frac{Z}{C}$$

where:

L = useful services life, in years

Z = thickness of allowable concrete loss over the reinforcing steel, in inches

C = corrosion rate, in inches/year. The maximum value should be used.

In pipe systems where corrosion has already occurred, the value for Z should be diminished to indicate actual allowable concrete loss. When dealing with other pipe materials, such as asbestos cement, non-reinforced concrete pipe, or ferrous pipe, the estimate of useful life should be based on the amount of remaining pipe wall which can be corroded before failure occurs. It is important to remember that all pipe is designed to support the soil load plus a live load and an appropriate factor of safety. Rigid pipe such as asbestos cement, reinforced concrete, non-reinforced concrete, cast iron and vitrified clay does not require side support, but flexible pipe such as ductile iron, steel, polyvinyl chloride, polyethylene, fiber reinforced plastic and reinforced plastic mortar pipe do require lateral soil support. As with other types of failure analysis, suitable factors of safety should be utilized in determining useful life expectancy prior to failure.

4.5.3 Reliability of Predictive Models

Two studies were reviewed to assess the accuracy of corrosion modeling: the San Diego - West Point Loma interceptor in the City of San Diego, California, and the Sacramento Central Trunk Sewer in Sacramento County, California (4). The results of these two studies are indicative of the current status of the Pomeroy predictive model equations: The San Diego - West Point Loma analyses estimated the reinforcing steel in the 114-inch diameter sewer pipe would be exposed in six years, and the reinforcing steel was actually exposed in a period of seven years; for the Sacramento Central Trunk Sewer, however, the actual maximum crown corrosion was two to five times less than the model predicted in the upper reaches, but only one to two times less in the lower sewer reaches.

Predictive models have been found to be accurate in some cases, particularly when peak corrosion and turbulence factors are utilized and the effect of sidestreams are considered. A factor of safety may also be incorporated.

Due to the possibility of several factors which can compound the difficulty in predicting sulfide generation, such as sewer blockages, grit and slime layer buildup, only actual measured sulfide concentrations should be used as input to the model to estimate the corrosion rate. As with all predictive models, actual measurements of corrosion penetration should be taken to confirm and calibrate corrosion model equations over time for any area under investigation.

4.6 References

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4. Sulfide in Wastewater Collection and Treatment Systems, ASCE Manual No. 69, American Society of Civil Engineers, New York, NY, 1989.
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5. ALTERNATIVES FOR CONTROLLING HYDROGEN SULFIDE CORROSION IN SEWERS

5.1 Prevention of Hydrogen Sulfide Corrosion in Existing Sewer Systems

5.1.1 Introduction

This chapter presents the available techniques for controlling sulfide in sewage collection systems. A step-by-step approach to the analysis of alternatives is suggested in this document for a municipality experiencing corrosion or odor problems in the wastewater collection system. Hydrogen sulfide corrosion problems in wastewater treatment plants are addressed in Chapter 6. Control techniques presented in these two chapters may be applicable to either collection systems or treatment plants.

In sewer systems, hydrogen sulfide corrosion control can be achieved by the following techniques:

1. Oxidation of hydrogen sulfide in the wastewater, involving air or oxygen injection or addition of oxidizing chemicals such as hydrogen peroxide (H_2O_2), chlorine (Cl_2) or potassium permanganate ($KMnO_4$).
2. Precipitation with metallic salt, such as ferrous chloride ($FeCl_2$) ferrous sulfate ($FeSO_4$). The dissolved sulfide is converted to an insoluble precipitate, thus preventing release of H_2S gas.
3. Elevation of pH through shock treatment with caustic to inactivate the sulfate-reducing bacteria in the slime layer.

The mechanisms of hydrogen sulfide corrosion were described in Chapter 2. Most control methods presented in this chapter are oriented toward reducing dissolved sulfide in solution, and therefore, minimizing the release of hydrogen sulfide gas into the sewer atmosphere. It is important to understand that reducing dissolved sulfide levels by some percentage does not necessarily reduce the rate of corrosion by the same proportion.

No single control system is the most cost-effective in all situations. Selection of a sulfide control technology for a particular collection system depends upon site specific conditions, such as dosage rate, availability of chemical, wastewater characteristics, and sewer system characteristics. In fact, multiple types of control processes are often used within one collection system.

Basic goals and treatment levels for any collection system should be established after identifying the extent of the problem. Treatment objectives may be developed for each system, but from experience, these guidelines are offered:

1. Maintain dissolved oxygen greater than 0.5 mg/l.
2. Keep dissolved sulfide less than 0.1 to 0.3 mg/l. While 0.1 mg/l is preferred, it may be difficult and costly to achieve.
3. Maintain hydrogen sulfide in the air at less than 3 to 5 ppm.
4. Increase pipe crown pH to 4.0 or higher.

Techniques available to control hydrogen sulfide corrosion have been categorized as follows:

- Oxidation Systems
- Precipitation Systems
- pH Elevation
- Other Methods

These techniques are summarized in Table 5-1, and are discussed below (1):

TABLE 5-1

SUMMARY OF HYDROGEN SULFIDE CONTROL TECHNIQUES

Technique	Frequency of Use	Cost Factors	Advantages	Disadvantages
I. OXIDATION				
Air injection	Low; limited by application	Power only	Low cost, adds DO to wastewater to prevent further sulfide generation	Applicable only to force mains; potential for air binding. Limited rate of O_2 transfer
Oxygen injection	Low in U.S.; high in U.K., Australia	Liquid oxygen and storage	5 times solubility of air; high DO possible; economical in force mains	Applicable only to force mains; achieving good O_2 transfer may be difficult
Hydrogen peroxide	High	Dosages for oxidation of all components	Effective for odor/sulfide control in gravity sewers or force mains; simple installation	Costs can be high if dosages much greater than stoichiometric amount for sulfide oxidation
Chlorine	High	Dosages for oxidation	Applicable to gravity sewers or force mains	Safety considerations
Potassium permanganate	Low	Chemical cost	Effective, powerful oxidant	High cost, difficult to to handle
II. PRECIPITATION				
Iron salts	High	Availability of low cost material; freight charges	Economical for sulfide control in gravity sewers or force mains	Does not control non-H_2S odors; sulfide control to low levels may be difficult; dosages variable
Zinc salts	Low	Chemical avail-	Lower solubility	Zinc discharge is regulated
III. pH ELEVATION				
Sodium hydroxide (shock dosing)	Medium	- Chemical cost - Storage - Frequency of use	Intermittent appl. may be acceptable. Very simple, little equipment required	Special handling of high pH slug may be required at treatment plant.
IV. OTHERS				
Nitrate formulations	Low	Chemical cost	Provides source of O_2	
Sewer ventilation	Very low	Power Odor Control	Helps maintain a safe, sewer environment	May not be practical except on interceptors; not proven

5.1.2 Oxidation Systems

5.1.2.1 Air Injection

As discussed in Chapter 2, sulfide is produced by anaerobic bacteria that reduce the sulfate which is normally present in sewage. Dissolved oxygen levels above 0.5 mg/l can generally prevent sulfide formation. Sulfide can still be produced within the slime layer, but if dissolved oxygen is present, sulfide will be oxidized as it passes into an aerobic environment. If dissolved oxygen is not present, dissolved sulfide will enter the bulk wastewater where it can be present as dissolved hydrogen sulfide gas (H_2S).

Aeration can be a cost effective method for controlling sulfide generation, but unless air is introduced by passive means, such as the presence of turbulent conditions in the system, equipment must be provided to compress and to introduce it into the sewage. Advantages include a reduction of BOD in sewage and non-toxicity. In pressurized lines, a gas pocket may develop and cause localized problems if inadequate oxygen transfer has occurred, even when well-protected by air release valves. Air injection is most commonly applied to force mains and wet wells.

When using an air injection system, it is necessary to:

1. Estimate the oxygen required for the bulk wastewater (mg/l of O_2) by measuring oxygen uptake rate in the laboratory at the expected detention times.
2. Estimate oxygen required for the slime layer.
3. Determine air flow needed.
4. Select type of air injection, such as direct injection into the force main or dissolution in a U-tube.

5.1.2.2 Oxygen Injection

Because pure oxygen is five times more soluble in water than air, it is possible to achieve higher DO levels in sewage by injecting pure oxygen instead of air. Pure oxygen may therefore a more effective method of sulfide control for cases where the total oxygen requirement exceeds that which can be transferred using air injection. Use of pure oxygen as a sulfide control measure is particularly advantageous in pressurized systems, because dissolution of oxygen is greater at higher pressures. Since less oxygen gas is required than air to achieve the desired DO levels, the potential for gas pocket generation in force mains is substantially reduced.

Pure oxygen systems typically include a liquid oxygen storage vessel, vaporizer, pressure regulator, oxygen feed and injection systems, and a control system. Most of these components can be leased from an oxygen supplier. Oxygen can be injected: 1) in a pressurized side stream, which is mixed with the main flow; 2) through a U-tube oxygen dissolver which increases dissolution of oxygen at the greater pressures; or 3) directly at a pump discharge or force main.

Studies have shown that oxygen will oxidize dissolved sulfides (DS) depending on the dosage. For example, a typical design guide is to provide 5 mg O_2/mg DS for oxidation and then enough additional oxygen to meet the oxygen uptake rate of the wastewater and slime layer (2). The location of oxygen injection systems is usually at the pump discharge.

5.1.2.3 Addition of Hydrogen Peroxide

When hydrogen peroxide (H_2O_2) is added to wastewater, it oxidizes dissolved sulfide and decomposes to water and oxygen, thus keeping conditions aerobic. Dosage rates range from 1 to 5 lb H_2O_2/lb sulfide, depending upon degree of control, wastewater characteristics, sulfide levels and length of time involved between the injection and sulfide control point (3).

Equipment used for H_2O_2 addition is relatively simple, consisting mainly of storage and feed components. It must be made of corrosion-resistant material since H_2O_2 will react vigorously with contaminants such as iron and organic materials. It is usually fed from 50 gallon drums or from bulk storage tanks directly into the sewage and is typically available as 35% and 50% solutions. It may be necessary to add the chemical at several points along the sewer. Generally more H_2O_2 is required if sewage remains in the line for more than 90 minutes. Time required for reaction with dissolved sulfide is about 15-30 minutes and is slower at lower sulfide concentrations, particularly below 1 mg/l. Protective gear must be worn when handling hydrogen peroxide.

5.1.2.4 Addition of Potassium Permanganate

Potassium permanganate is a strong oxidizing agent which oxidizes sulfide. It is normally supplied in a dry state, and is fed as a 6% solution in water. Therefore, equipment for dissolving and feeding it must be supplied. Protective gear must be worn by personnel handling the material. Because it is a strong indiscriminate oxidizing chemical, the dose ratio required to achieve sulfide control can be higher than the stoichiometric weight ratio of 6.5:1.

5.1.2.5 Addition of Chlorine

Chlorine will oxidize sulfide to sulfate or to elemental sulfur, depending on pH. It is added at a dosage rate of 10 to 15 lb Cl_2 per lb H_2S removed (3). Its effectiveness is frequently reduced because of reactions with other components in sewage. It may be added as an aqueous solution (sodium hypochlorite) or directly as a gas, using equipment similar to that installed in wastewater treatment plants for effluent disinfection.

Wastewater treatment personnel are well acquainted with chlorine, and since it is already being purchased, there may be a tendency to use it in collection systems, as well as in the wastewater treatment plant. However, application sites will often need to be located in residential or commercial areas; therefore, safety in these areas should be considered.

5.1.3 Precipitation Systems

5.1.3.1 Iron Salts

Iron salts such as ferrous chloride and ferrous sulfate react with sulfide to produce an insoluble precipitate, and are added to wastewater to prevent the release of H_2S into the sewer atmosphere. Dosages are usually dependent on initial sulfide levels, but will generally range from 4 - 15 lb Fe/lb sulfide (4). Iron salts may be received as dry chemicals and dissolved in water for ease of injection, but more commonly they are purchased as a solution.

Ferrous chloride and ferrous sulfate are often purchased in bulk, usually in a 40% solution, and being acid in nature, they must be stored in corrosion resistant tanks and fed through corrosion resistant lines. A typical feed system involves feeding the iron solution at multiple rates in relation to diurnal fluctuations in dissolved sulfide and flow rate.

Ferrous salts will also precipitate phosphorus compounds. When used in sewage systems, the insoluble phosphates will be removed in the treatment plant settling tanks. Use of iron salts may be particularly suitable for those systems where limitations exist for phosphorous discharged in the plant effluent.

5.1.3.2 Other Metallic Salts

Other metallic salts will also produce insoluble sulfides. In general they are more costly than iron salts. Zinc salts have been used, but since effluent standards and sludge disposal regulations frequently include zinc limitations, these salts are not usually recommended.

5.1.4 pH Elevation

The amount of hydrogen sulfide gas in solution is negligible at a pH above 9.0, since the sulfide present is nearly entirely in its ionic form (HS^-). However, continuous feeding of sodium hydroxide (NaOH) to maintain an elevated pH is expensive and may disrupt downstream treatment processes.

The most effective use of sodium hydroxide (caustic soda) is shock treatment of sewers to produce a pH of 12.5 to 13.0 in the wastewater for a period of 20 to 30 minutes (3). Such a high pH inactivates sulfate reducing bacteria in the slime layer for a period of a few days to one to two weeks. The high pH slug may have to be isolated at the WWTP and fed slowly into the system if it is not diluted in the collection system.

Shock treatment with sodium hydroxide requires little equipment. It is necessary only to send a tank truck to the injection point (upstream as far as possible) from which liquid caustic soda is added by gravity over a short period of time at a rate sufficient to keep the pH elevated. As with acidic materials, protective gear should be worn by personnel handling sodium hydroxide to avoid skin and eye contact.

In some cases, it may be important to mechanically scrape the slime layer in the sewer before performing the first treatment. The caustic slugging method of treatment usually provides less direct control of H_2S because of the cyclic build-up and destruction of sulfide, but can be cost-effective.

Another approach to corrosion control using NaOH is one developed by the County Sanitation Districts of Los Angeles County. This involves direct spraying of the pipe crown with caustic soda to neutralize the sulfuric acid. The process, which was still experimental at the time this document was prepared, consists of a floating raft to which is mounted a spray head. Caustic soda is pumped from a truck though a hose to the spray head, which applies the chemical to the pipe crown. Preliminary data indicate that the process is effective and economical. After application of caustic, pH of the crown surface decreased by an average of 0.1 pH unit per day. The Districts are proceeding with procurement of a trailer-mounted, self-contained caustic spray delivery system (5).

5.1.5 Other Methods

5.1.5.1 Chemical and Physical Techniques

Use of sodium nitrate and formulations containing nitrate have been successfully used for sulfide control. The presence of nitrate suppresses sulfide generation because anaerobic bacteria preferentially use the nitrate ion before sulfate as a source of oxygen (1). A proprietary formulation containing nitrate has been shown to be a cost-effective alternative for sulfide control at several locations in the United States (6).

Treatment with special bacteria may suppress the action of sulfate reducing bacteria or may promote the destruction of the slime layer. While successful in the laboratory, such cultures have shown only limited success in the field.

Limited success has been reported in physically removing the slime layer. At high flows, the slime layer erodes, but this is seldom relied upon as a practical control method in existing systems. Likewise, submerging sewers may prevent corrosion in the submerged reaches, but generation of sulfide is likely to increase due to increased detention times and less opportunity for reaeration.

5.1.5.2 Sewer Ventilation

Two of the requirements for hydrogen sulfide corrosion to occur are the presence of hydrogen sulfide within the sewer atmosphere and damp conditions along the sewer walls to support microbiological activity. Sewer ventilation can minimize the potential for hydrogen sulfide corrosion in two ways:

1. Ventilation can reduce hydrogen sulfide concentrations in the sewer atmosphere by dilution of the sewer air.
2. Ventilation can reduce humidity levels along sewer pipe and structure walls.

Natural sewer ventilation is provided in all gravity sewer systems, whether the ventilation mechanism is through house vents, as is prevalent in the United States, or when building sewers contain house traps, through special ventilation stacks as in the United Kingdom and Australia (7)(8). Provisions for separate venting must also be provided for inverted siphons and often flooded sewer sections (Refer to Figure 5-2). Natural sewer ventilation occurs through any of the mechanisms listed below.

- Relative difference in air density between the sewer atmosphere and outside air.
- Frictional drag of the wastewater at the air/liquid interface.
- Rise and fall of wastewater level within the sewer .
- Changes in barometric pressure along the sewer.
- Induced air currents caused by wind velocity past vents.

The extent of natural ventilation available within a given sewer is difficult to predict and highly variable due to the number of factors which can affect it. Thistlethwayte has recommended a minimum of 0.05 cubic feet per minute of natural air flow for each square foot of sewage surface to control sewer ambient humidity levels to less than 85%, though he states that ventilation alone may not prevent corrosion (8). In addition, the discharge of hydrogen sulfide-laden sewer air will likely lead to complaints unless significant odor treatment is provided. For these reasons, natural ventilation is not a likely means by which to effectively control either hydrogen sulfide concentration or humidity within a given sewer.

Mechanical ventilation has been used with claims of at least some success at various installations, including Austin, Texas (9), Los Angeles, California (10) and Sydney,

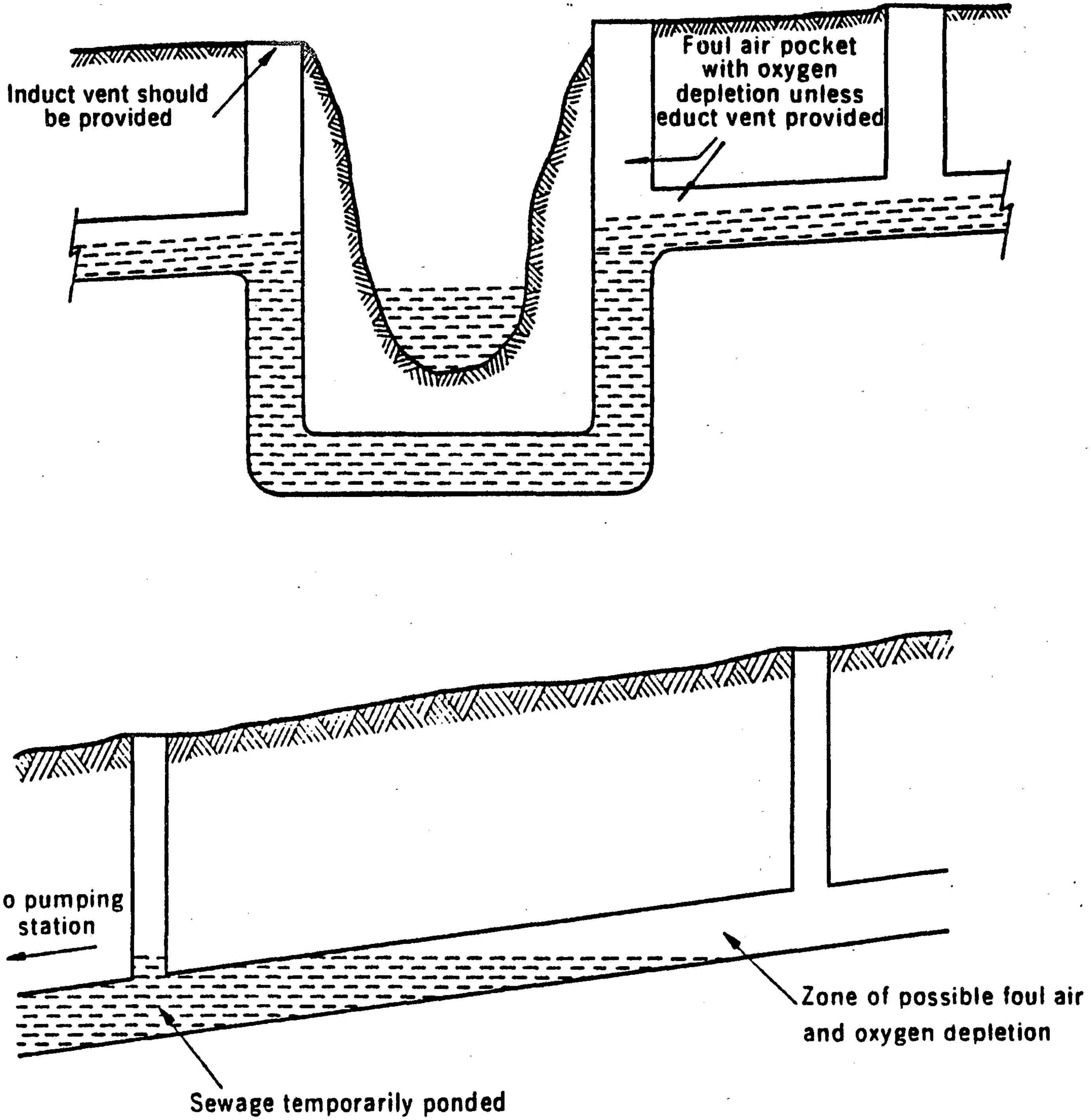

Figure 5-2. Ventilation Problems of Filled Sections of Sewers

Australia (7). At the Hyperion wastewater treatment facilities in Los Angeles, an 8-mile long sewer was provided with fans to provide 17,000 cfm air flow to control corrosion and maintain negative pressure within the sewer. The Austin, Texas sewer system originally contained two separate mechanical ventilation systems which were installed in 1965; one system serviced approximately 19,600 ft of a 42-inch influent gravity sewer to a pump station, and the other system serviced an inverted siphon. The air from both systems was originally discharged into aeration tanks at the treatment facilities.

Subsequent discussions with City of Austin staff indicated that the gravity sewer system was abandoned many years ago. The siphon, commonly referred to as the Walnut Creek/Cross-Town Tunnel, was recently discovered to have severe corrosion problems, likely as the result of the installation of several large interceptors within the past few years. The successful results reported prior to that may have been more the result of good engineering practice than due to forced ventilation. The tunnel project was bored; consequently, any dips in grade or changes in alignment were gradual. In addition, the upper reaches of the sewer contained a cunette for self-cleansing velocities at low flow. The sewer was also lined for a distance of 200 feet each way from drop shafts. Finally, energy dissipators were installed at major intersections, along with air exclusion gates in combination with adjustable air orifices.

Mechanical ventilation may have a limited effect in sewers which contain numerous house vents, influent sideline sewers or other air sources. Also, as fresh air travels along a sewer and becomes saturated, the rate of absorption will become less and deposition of moisture will occur. Properly sized, a mechanical ventilation system might be capable of reducing the relative humidity to less than 85%, but if the humidity of the outside fresh air source is greater than 70%, more frequent air changes will be required to attain the same result (8).

5.2 Sulfide Control Systems Used in the United States

5.2.1 Summary of Control Systems Used by Selected Cities

The sulfide control techniques used by selected communities in the U.S. are listed in Table 5-2. In most cases, personnel in these cities are willing to provide more information to another community to help them solve their hydrogen sulfide corrosion problems, or to better understand the available technologies.

5.2.2 Case Histories

1. Sulfide Control with Ferrous Chloride ($FeCl_2$) in Large Diameter Sewers - County Sanitation Districts of Los Angeles County (4)

Ferrous chloride addition was partially effective in reducing corrosion in large diameter (54-144 in.) sewers based on full scale testing and an interim installation for three outfalls leading to the Joint Water Pollution Control Plant in Los Angeles County, California. $FeCl_2$ dosages varied for each outfall, depending on the concentration of dissolved sulfide present as shown below:

$FeCl_2$ Dosage for 90% Dissolved Sulfide Removal

(November, 1988)

Dissolved Sulfide Level	Estimated Ratio of Ferrous Chloride to Dissolved Sulfide
4 mg/l or greater	7:1
1 - 4 mg/l	15:1
less than 1 mg/l	100:1

Testing performed during full scale demonstrations included monitoring dissolved sulfide, pH, temperature, dissolved oxygen and iron. Hydrogen sulfide levels in the sewer atmosphere were reduced, but not in proportion to dissolved sulfide removals.

TABLE 5-2

HYDROGEN SULFIDE AND CORROSION CONTROL SYSTEMS USED BY SELECTED CITIES IN THE U.S

CITY	CONTROL METHOD USED	REFERENCE*
Albuquerque, NM	Cl2 Inject., H2O2 Inject., O2 inject., KMNO4 Inject.	3
Altamonte Springs, FL	FeSO4 Injection	11
Antioch, CA	O2 Injection	12
Austin, TX	Sewer Ventilation	9
Baton Rouge, LA	Cl2 Injection	3
Battle Creek, MI	Air Injection, KMnO4 Injection	3
Bayville, NJ	Air injection, Cl2 Injection	
Broward County, FL	Cl2	13
Casper, WY	NaOH Injection	3
Cedar Rapids, IA	NaOH Injection	20
Charlotte, NC	H2O2 Injection	3
Colorado Springs, CO	H2O2 Injection	
Dallas, TX	Min. Pipe Slope. Corr. Resist. Mat'ls.	3
Denver, CO	H2O2 Injection	3
Duluth, MN	Corr. Resist. Materials	3
El Paso, TX	O2 Inject., KMnO4 Inject., Corr. Resist. Mat'ls	3
Farifax, VA	H2O2 Injection	
Fayetteville, AR	NaOH Addition, FeCl2 Injection	14
Fort Lauderdale, FL	Air Injection, H2O2 Injection	
Fort Worth, TX	H2O2 Injection, KMnO4 Injection	3
Greensboro, NC	Air Injection	
Hilton Head Island, SC	FeSO4 Injection	11
Honolulu, HI	Corr. Resist. Materials, Cl2 &H2O2 Injection	3
Indianapolis, IN	FeSO4	3
Jefferson Parish, LA	O2 Injection	
Keene, NH	O2 Injection (U-tube)	
Knoxville, TX	Cl2 Injection	
Lake Worth, FL	FeSO4 Injection	11
Lakeland, FL	Corr. Resistant Materials	15
Little Ferry, NJ	H2O2 Injection	
Los Angeles, CA	Air Inject., NaOH Slugging, FeCl2 Inject.,Sewer Ventilation	4,10,12
Louisville, KY	FeCl2 Injection	
Mesa, AZ	FeCl2 Injection	12,16
Milwaukee, WI	NaOCl Injection	3
Mineola, NY	Flooding lines	
Myrtle Beach, SC	Ozone Injection	
Nashville, TN	Corr. Resistant Materials, FeSO4 Injection	3
Omaha, NE	FeCl3 Injection, NaOH Slugging	3
Orlando, FL	H2O2 Injection	3
Phoenix, AZ	Cl2 Injection, H2O2 Injection, Air Injection	3
Pine Bluff, AR	Unspecified Chemical	3

TABLE 5-2 (Cont.)

CITY	CONTROL METHOD USED	REFERENCE*
Raleigh, NC	Cl2 Inject., Corr. Resist. Mat'ls.	3
Sacramento, CA	Cl2 Injection, H2O2 Injection, Air Injection	12
San Antonio, TX	Air Injection, H2O2 Injection	3
San Diego, CA	Corr. Resist. Materials	3
Seattle, WA	H2O2 Injection, Air Injection, Corr. Resist. Mat'ls.	3,17
St. Louis, MO	Air Injection, H2O2 Injection	3
Tampa, FL	Upspecified Chemical	3
Tempe, AZ	Caustic slugging	
Virginia Beach, VA	Cl2 Inject., NaOH Inject., H2O2 Inject., Corr. Resist. Mat'ls.	3
West Palm Beach, FL	H2O2 Injection	12
Yuma, AZ	FeCl2 Injection	18

* REFERENCES – AT CONCLUSION OF THIS CHAPTER

The District measured a one unit increase in pH on the pipe crown and estimated corrosion at the rate of 0.2 in/yr, which was a three fold decrease in corrosion rate due to $FeCl_2$ addition. The District also estimated that dissolved sulfide was reduced by 70-90% to a range of 0.2-0.5 mg/l, and H_2S was reduced by 50-70% in the sewer atmosphere.

A cost of $700,000 was estimated for three installations to cover 75 miles of sewer. An annual cost of $2.5 million was projected for 90% sulfide control.

Sulfide Control with Hydrogen Peroxide - City of Clearwater, Florida (19)

The City of Clearwater, Florida uses hydrogen peroxide (H_2O_2) in the collection system to control odor and corrosion. The long force mains from the beach area to the main pump station and wastewater treatment plant have a detention time of greater than four hours. H_2O_2 is dosed at three locations as shown on Figure 5-3.

H_2O_2 has been used in this system since 1984. The long force mains allowed significant amounts of dissolved sulfide (8.5 mg/l) to be generated. Corrosion also occurred in sections of the force mains that were not flowing completely full.

The results of the sulfide control system have been to maintain dissolved sulfide at 0.4 - 0.8 mg/l over the past several years (1986 - 1989) and H_2S in atmosphere of the Bay Front Pump Station at about 1 ppm. Dosages are reported to be averaging 1.5-1.6 lb H_2O_2/lb dissolved sulfide.

Sulfide Control with Pure Oxygen - Jefferson Parish, Louisiana

Jefferson Parish uses direct oxygen injection systems in a large collection system comprised of over 500 pump stations. The oxygen is injected to maintain aerobic conditions in the system tributary to the treatment plant, to reduce sulfide levels, and to control H_2S at the plant to 5 ppm as inlet air to the odor control scrubbers.

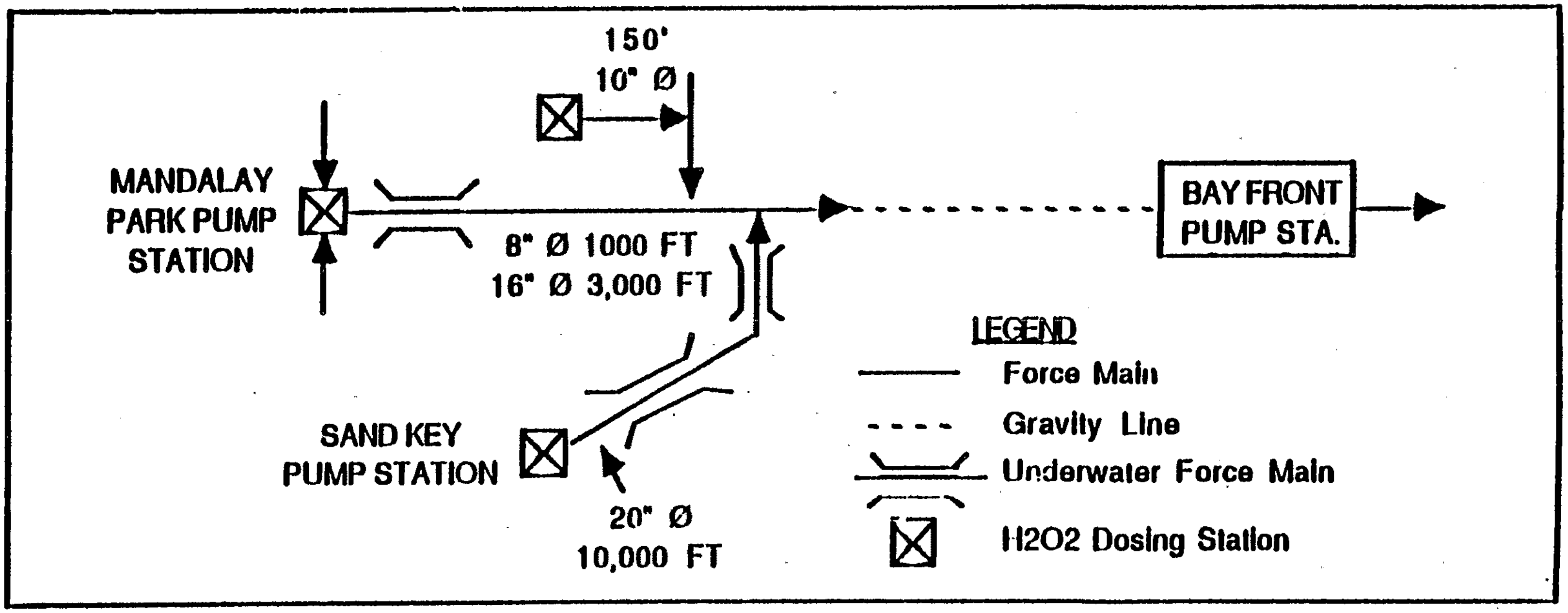

FIGURE 5-4. MAP SHOWING LOCATIONS OF H_2O_2 DOSING STATIONS

Each direct injection installation includes a liquid oxygen storage tank, vaporizer, control unit and injection diffusers in the force mains. Oxygen is fed continuously, based on the pumps running, and the dosage is increased using a timer to meet peak demands. The systems were started up in 1988 and 1989 and are still being tested and optimized. The current cost (August, 1990) for liquid oxygen is about $0.03/lb and the City spends about $200,000/year on oxygen for the entire system. The largest installation is being expanded from a 600 cfm to a 1200 cfm oxygen injection rate. One problem currently experienced is diffuser plugging.

In the upstream areas of the collection system, ferrous chloride is added to remove existing sulfide to supplement the control program using pure oxygen. Other corrosion control techniques used at this location include corrosion-resistant liners in the collection system.

Sulfide Control with Caustic Slugging - Cedar Rapids, Iowa (12)

The City initiated caustic slugging in 1985 on the 5.9 mile, 84 in. and 94 in. gravity interceptor sewer to the Cedar Rapids Water Pollution Control Facility, and has continued with the operation through 1990. A tanker load of 50% caustic is dumped during a 20 -30 minute period in the early morning at a point well upstream of the plant.

The objective is to inactivate the slime layer in the pipe to reduce sulfide levels. The pH is elevated to about 12.5 and arrives as a slug at the plant. During the early years of operation, a primary clarifier was set aside to receive and store the material. However, now only the pH through the plant is monitored and no negative effects have been reported.

In 1985, data were collected on the sulfide levels at the plant. The cyclic nature of the sulfide reduction/build-up is seen in Figure 5-4. Currently, the operation is repeated every 2-3 weeks or is slugged with caustic when sulfide levels reach 2 mg/l at the treatment plant.

The City reports that the cost of caustic has doubled since 1985 (current price is $0.19/lb

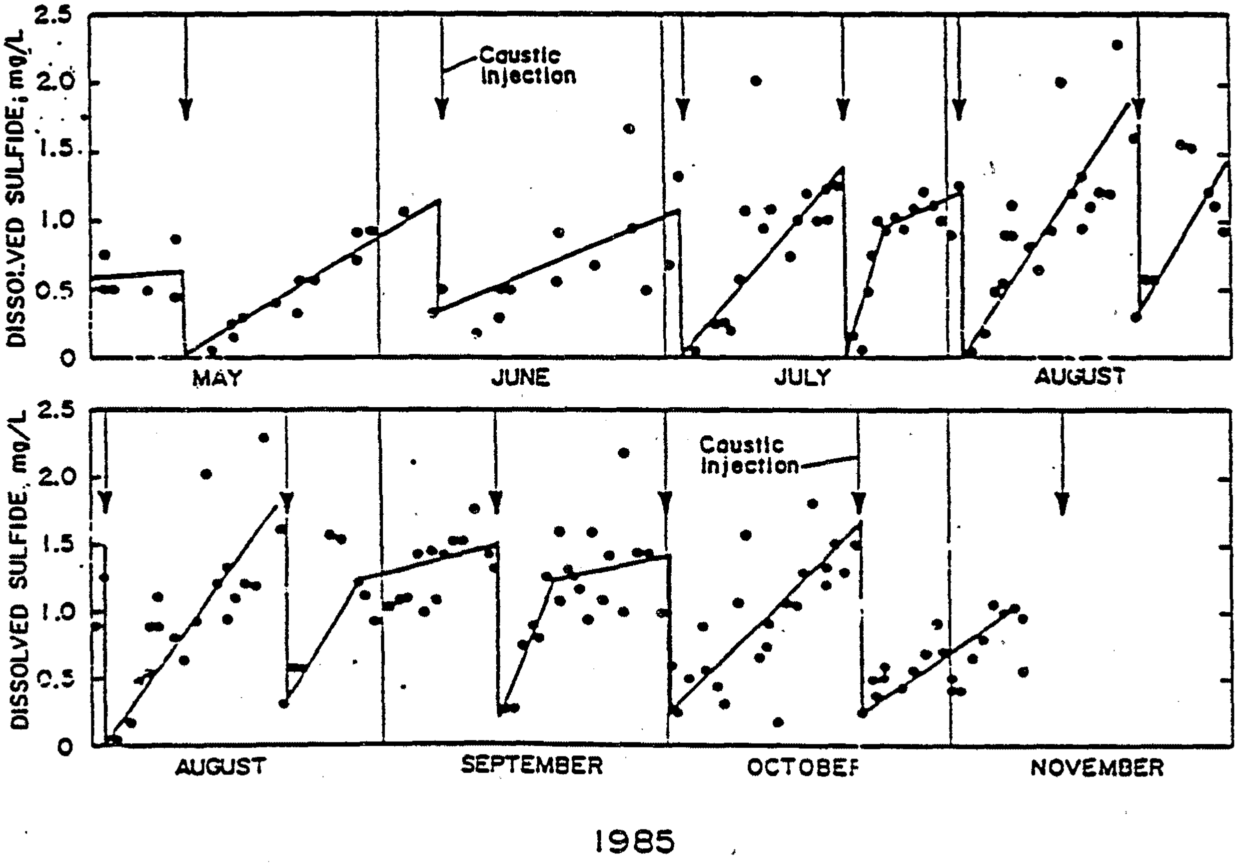

FIGURE 5-5

DISSOLVED SULFIDE LEVELS (USING CAUSTIC SLUGGING), MAIN INTERCEPTOR - CEDAR RAPIDS, IOWA as 100% NaOH), and therefore, it is considering other sulfide control strategies in conjunction with caustic slugging, or in place of slugging. The City will initiate field inspections for corrosion in the collection system in 1991 but reports that corrosion is not a significant problem. The City does not store NaOH because of the need to control temperature to prevent crystallization of the product, which occurs at approximately 40°F.

5.2.3 Chemical Costs

The following are typical costs for chemicals commonly used for sulfide control:

Chemical	Range of 1990 Costs for Chemicals ($/lb)	Range of Reported Dosage Rate: (lb Chemical per lb H_2S Removed)
Ferrous Chloride	0.08 - 0.36[a]	4-15
Pure Oxygen	0.03 - 0.12[b]	5-10
Hydrogen Peroxide	0.34 - 0.75[c]	1-5
Potassium Permanganate	1.23 - 1.28[d]	6-7
Chlorine	0.20 - 0.33[e]	10-15
Sodium Hydroxide	0.18 - 0.25[f]	pH = 12.5

NOTES

(a) Costs are per lb as $FeCl_2$ which will vary from 25-35% (specific gravity 1.3 - 1.44) and iron content will vary from 10-15%. The range in prices is due to freight charges as a commodity chemical. Costs will be quoted from suppliers by iron content or per gallon.

(b) Costs are per lb of pure oxygen. Prices are quoted per 100 cu ft and there are 8.28 lbs O_2/100 cu ft. The range of prices is from very large to very small quantity of purchases. Rental of liquid oxygen storage tanks can cost from about $500 - $2,000/mo. (1,500 - 13,000 gal. storage tanks).

(c) Reported as 100% H_2O_2, but is purchased as 35 or 50% solution. Cost range is due to freight charges.

(d) Reported per lb of $KMnO_4$ and is based on 24,000 lb minimum annual usage. Costs do not include freight charges which are variable.

(e) Reported per lb of chlorine for one ton cylinders, depending on quantity purchased and freight. Chlorine costs are very low in some states.

(f) Costs are per lb 100% NaOH, but is delivered as 50% solution. Range is dependent upon freight charges, and is reported for bulk deliveries. Fifty-five gallon drums cost about $0.40-$0.50/lb as NaOH.

It must be emphasized that material cost is only one element of total treatment cost. It is necessary to add labor, capital costs, utilities and maintenance to determine total treatment cost.

5.3 Procedure to be Followed in Selecting Corrosion Control Method(s)

5.3.1 Bench Scale Testing and Preliminary Cost Analysis of Alternatives

Using actual wastewater samples containing typical sulfide levels, jar tests can be conducted in the laboratory to estimate pounds of chemical needed per pound of H_2S removal. Such results will not always correspond to quantities needed in the field because other reactions are taking place, such as natural introduction of oxygen. Moreover, the slime layer which exists in a sewer cannot be reproduced accurately in the laboratory. The laboratory tests will serve to eliminate candidates which perform poorly and will help in sizing equipment to be used in field tests.

As mentioned previously, reviewing control methods used in similar collection systems is a good start for evaluating control alternatives. In discussing the problem with personnel from other facilities, or in reviewing the literature, some systems may be initially eliminated. Selection of viable alternatives will then depend on cost, unless other factors such as introduced hazards may eliminate others.

While some chemical costs are listed in Section 5.2.3, actual cost in a particular location depends upon such factors as quantity required, distance from a source of supply, etc. Chemical supply representatives should be contacted for current quotations. The supplier can often provide information on the type of equipment recommended for storage and feeding of chemicals. A rough estimate of investment costs should be made which should include chemical cost, capital carrying charges, labor, miscellaneous supplies, utilities, and an allowance for maintenance.

5.3.2 Field Demonstration of Best Control and Lowest Cost Alternatives

A field test of likely alternatives is generally mandatory. Frequently, suppliers can advise on how their product can be tested economically, and they will lease equipment. A test site(s) should be selected for an injection point upstream of a section of the system where hydrogen sulfide corrosion is known to be taking place.

The reaction time required for the chemical should be estimated. For example, $FeCl_2$ requires about 20 minutes and H_2O_2 about 30 minutes. Select the location for chemical addition and assess if two or more points of injection are required, because of downstream distances or sulfide generation that is occurring downstream. Add more chemicals to account for predicted downstream generation.

The full scale tests should be set up to provide sufficient monitoring of performance. Therefore, analyses of dissolved sulfide, total sulfide, DO, pH, temperature, and atmospheric H_2S should be tested. In some cases, such as when using iron salts, the wastewater should be tested for residual iron levels. Offset testing can be considered where a theoretical slug of sewage is monitored as it travels between test locations to get a "snapshot" of the effectiveness of the product over time and distance. Dyes are used to verify that a sample is taken of the same slug as it travels downstream.

Record dosages of the chemical, and using the data, prepare tables that relate each location on the reach to (1) the dosage ratio of product to dissolved sulfide, (2) dissolved sulfide without treatment, (3) dissolved sulfide with treatment, and (4) sulfide reduction. Assess the dissolved sulfide:total sulfide ratio before and after treatment. Plot dissolved sulfide and atmospheric H_2S for each location with and without treatment.

Perform tests of crown pH after one week to determine any changes to background levels. Consider follow-up testing to assess rates of corrosion (in/yr) by the sampling techniques previously presented.

5.3.3 System Selection

Performance criteria need to be established, but are sometimes difficult to achieve or verify. For example, to control hydrogen sulfide corrosion, the following objectives may apply to a particular system or sulfide control program:

- Maintain DO greater than 0.5 mg/l to eliminate sulfate reduction, or increase ORP to + 100 mv
- Reduce dissolved sulfide to 0.1 to 0.3 mg/l.
- Reduce H_2S (in sewer air) to less than 3 to 5 ppm to reduce corrosion rate.
- Increase crown pH to 4.0 or greater.

Field tests of dosages and local chemical costs are used to determine the cost per pound of dissolved sulfide removed. Also, the performance of each product, according to the desired performance standard, is required in this evaluation. The selection of a performance standard is site specific.

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6. ALTERNATIVES FOR CONTROLLING HYDROGEN SULFIDE CORROSION AT PUMP STATIONS AND TREATMENT FACILITIES

There are primarily three methods by which hydrogen sulfide corrosion can be controlled; by minimizing the generation and release of hydrogen sulfide, by the use of paints and other protective coatings and linings and by the use of corrosion-resistant materials. These alternatives and some of the more common examples which fall under each category are described in the following sections.

6.1 Control of Hydrogen Sulfide

Control of hydrogen sulfide can be accomplished by chemical addition as discussed in Chapter 5. This consists primarily of introducing materials to the wastewater to prevent sulfide generation, to oxidize or precipitate existing sulfide compounds, or to temporarily adjust pH to discourage sulfide generation.

Ventilation of corrosive atmospheres is generally not practiced on gravity sewer systems (except in the case of inverted siphons). However, ventilation is common in pump station wet wells, covered tanks and channels, though it is normally provided to minimize the potential buildup of flammable gases and to ensure a safe working environment for human exposure rather than for protection from hydrogen sulfide corrosion. Many of these systems are not of sufficient capacity to maintain a fresh air supply on a continuous basis, because human activity within the confined area is minimal and infrequent. Often, only a vent stack or pipe is provided for release of noxious gases, and no positive air inlet is provided other than from the sewers entering and exiting the tank. In other cases where forced mechanical ventilation is provided, the equipment operates only when a door is opened. Even though ventilation (and particularly forced mechanical ventilation) can offer an effective method to minimize hydrogen sulfide accumulation, this is rarely practiced, and excessive corrosion may occur along the walls, and ceilings of these structures. Ventilation systems should be provided to ensure positive air changes occur continuously and at a moderate rate. The air flows collected may in turn be treated to reduce offsite odor impacts. In addition to providing adequate ventilation within enclosed areas, measures should be taken to minimize turbulence by providing drop pipes or other means for obtaining submerged inlets, thus preventing vertical liquid free fall. To prevent accumulation of grease and scum, outlets should not be submerged in quiescent tanks without skimmers. Grease is particularly offensive in odor, and some floating solids can contribute to the generation of hydrogen sulfide gas. Steps should also be taken to limit the amount of solids and debris allowed to collect on bar racks, screens, in wet wells, tanks, and channels, as discussed in Chapter 3.

Electrical enclosures can become severely corroded by hydrogen sulfide, either by virtue of their presence in a corrosive atmosphere, or by hydrogen sulfide migrating to the enclosures via unsealed electrical conduit. According to the Instrument Society of America (ISA), active sulfur compounds rank with inorganic chlorides as the predominant cause of atmospheric corrosion in the process industries (7). ISA has classified gaseous airborne contaminants based on the rate at which corrosive contaminates react with copper. The ISA Classification of Reactive Environments is presented in Table 6-1. The ISA classification indicates that only the G1 - Mild rating for contaminant levels (less than 3 ppb H_2S) presents an environment sufficiently well-controlled to preclude corrosion from affecting equipment reliability. It should be noted that the classifications are listed based on less than 50 percent relative humidity. The classification should be increased one severity level for each a) 10 percent increase in relative humidity over 50 percent, or b) relative humidity rate of change greater than 6 percent per hour.

Four methods are frequently utilized to minimize corrosion within electrical enclosures; 1) using gasketed enclosures to prevent entry of corrosive gases, 2) maintaining positive air pressure within the enclosures, 3) purging with nitrogen gas, and 4) using vapor corrosion inhibitors.

Gasketed electrical enclosures, such as NEMA 4X, which are rated watertight, dust tight

TABLE 6-1

INSTRUMENT SOCIETY OF AMERICA CLASSIFICATION OF REACTIVE ENVIRONMENTS BASED ON H_2S CONCENTRATIONS

Severity Level G1 ($H_2S < 3$ppb)

Mild - An environment sufficiently well-controlled such that corrosion is not a factor in determing equipment reliability.

Severity Level G2 ($H_2S < 10$ ppb)

Moderate - An environment in which the effects of corrosion are measurable and may be a factor in determing equipment reliability.

Severity Level G3 ($H_2S < 50$ ppb)

Harsh - An environment in which there is a high probability that corrosive attack will occur. These harsh levels should prompt further evaluation resulting in environmental controls or specially designed and packaged equipment.

Severity Level GX ($H_2S \geq 50$ ppb)

Severe - An environment in which only specially designed and packaged equipment would be expected to survive. Specifications for equipment in this class are a matter of negotiation between user and supplier.

and corrosion-resistant, are commonly used in corrosive areas. NEMA 4X enclosures require the use of conduit hubs or equivalent provision for watertight connection at the conduit entrance, and mounting provisions external to the equipment cavity. The enclosures must be closed properly in order to retain their rating. Commonly due to personnel inattention, the enclosure doors are not properly secured and internal corrosion results.

In order to offset the potential for leakage due to inattention or for added precaution, fans with an external clean air source can be used to maintain a positive air pressure within the enclosure. In this manner corrosive substances are much less likely to enter the enclosure. The key elements of this type of electrical enclosure corrosion protection include a constant power supply to ensure positive pressure is maintained by the fan, and a fresh air supply. At wastewater treatment facilities, air free from hydrogen sulfide may not be available.

As an alternative to maintaining pressure with clean air, nitrogen gas can be used. With this option, each panel, enclosure, or instrument case is connected to a low-pressure nitrogen supply, which serves to maintain positive pressure within the enclosures and thus minimizes exposure of the electrical equipment to corrosive ambient air.

Vapor corrosion inhibitors (VCI) consist of fogs, sprays, impregnated foams, plastic emitters, strips, powders and other vehicles by which ions are dispensed to create a molecular corrosion inhibition film. The VCI dissolves in the presence of moisture to form a water electrolyte. It vaporizes and condenses on exposed metal surfaces, and is claimed to be self-healing and self-replenishing. By effectively coating exposed metal surfaces through ionic attraction, the VCI protects metals from corrosive attack. The VCI are stated to have a useful life of up to 24 months, are compact and require no special installation tools or activation procedures. Data on their effectiveness against hydrogen sulfide attack is limited to case studies provided by the manufacturer. In one instance, a wastewater pump station was experiencing monthly call-outs to a sewage pumping station due to corrosion occurring on the contactor armatures. Upon installing VCI, the corrosion stopped, provided the cabinet doors were properly closed, as protection depends on vapor being trapped within the cabinet.

6.2 Protective Coatings and Linings

Protective coatings include paints, sacrificial coatings and chemical conversion coatings, while linings consist of polymeric materials (usually pre-cured) physically attached to the material being protected.

6.2.1 Protective Coatings

Protective coatings can be subdivided into three generic types:

1. Metallic Coatings
2. Non-Metallic Coatings
3. Chemical Conversion Coatings

All paint and coating systems require care in the selection of type of coating system to be used, surface preparation requirements, methods of application, wet film thickness, curing requirements and total dry film thickness. Of particular importance with paint systems are curing temperature and curing time prior to immersion.

All paint and coating systems are susceptible to corrosion attack. Paint and coating systems can be attacked by any of the mechanisms listed below.

- Water, in the presence of salts, is an electrolyte and hydrolyzes certain paint components. The paint strength and adhesive properties are reduced.

- Oils, greases and soaps contain solvents which can soften the paint or make it more susceptible to abrasion.

- Physical forces such as alternate wetting and drying, heating and cooling and freezing and thawing, especially at the water surface.

- Sunlight and abrasion can similarly degrade coating surfaces.

- Hydrogen sulfide gas may be able to penetrate paints and protective coatings which have been partially eroded by the wastewater stream and biological activity.

- Once hydrogen sulfide gas reaches steel, the buildup of corrosion products and gas can form blisters which rupture, thus providing a larger area for corrosion attack.

- Hydrogen sulfide in moisture can be biologically oxidized to sulfuric acid, which can attack through pinholes and other surface defects.

6.2.1.1 Metal Coating Systems

Metallic coating systems can be subcategorized further into galvanizing and electroplating systems. Galvanizing provides sacrificial protection of the base metal and is commonly performed by dipping the metal to be protected into a molten zinc or cadmium bath. The effective service life of zinc galvanizing is directly proportional to the thickness of the galvanized coating. Inorganic zinc coatings have also been developed and include sodium silicate, which provides good bonding with the base metal while producing stable insoluble corrosion byproducts.

Other metallic coating systems fall under the electroplating sub-category, whereby a thin copper layer is first applied to the base metal, and an impervious physical barrier is electrically bonded to the copper. Metals used in the electroplating process include aluminum, tin, lead, nickel/copper alloys, stainless steel, nickel, chromium and silver. Of these, nickel, chromium and silver coatings are frequently used for corrosion protection.

6.2.1.2 Non-Metallic Coating Systems

Non-metallic coating systems consist of vinyl, epoxy and silicone resin primers and paints. Paints can be further classified as either 1) thermoplastic, including asphaltic/coal tar and polyethylene, which are applied hot and cure by cooling, and 2) thermosetting, such as polyurethane and epoxy, which set by chemical reaction caused by a separate curing agent. All painting systems require great care in selection of paint type, surface preparation, wet film and total dry film thicknesses, and curing requirements (particularly temperature and time prior to immersion). In addition, recent volatile organic compound (VOC) regulations have been promulgated by the Clean Air Act amendments for 1992 and beyond. This has resulted in the modifications of paint and primer formulas. Its effect on corrosion protection, if any, likely will not be known for several years.

The most common painting systems used for submerged environments and corrosive atmospheres are coal tar epoxies and epoxy paints. There are probably more coal tar epoxy coatings on concrete at wastewater treatment facilities than any other coating system currently available. However, the County Sanitation Districts of Los Angeles County (CSDLAC) experience has been that coal tar epoxy coatings fail within a few years when subjected to sulfuric acid attack (5). Some have argued that the reason for failure of coal tar epoxies are twofold: 1) that microorganisms utilize the organic sulfur within the coal tar epoxy itself, and 2) that because coal tar epoxy has a significantly greater coefficient of thermal expansion, high induced stress in the concrete lead to premature failure (6).

Epoxy paint systems have been shown to be effective for submerged applications on steel and concrete. They are durable and provide excellent resistance to acids, alkalis, solvents, abrasion and impact. Upon exposure to sunlight, epoxy coatings chalk, but the integrity of the coating system is unaffected. Epoxies can be cured by heat or by internal polymerization with amines. Polyamides are more frequently used as a curing agent, however. They provide better adhesion, moisture tolerance and flexibility, and have a higher solids content than do the amines. A disadvantage of the polyamides is less chemical resistance than provided by the organic amine curing agents.

CSDLAC is conducting continuing studies to evaluate the effectiveness of various coating used for protecting concrete from sulfuric acid attack. The pilot scale study involves subjecting the coating, which is applied by the vendor to damp concrete, to a solution of 10 percent sulfuric acid. The study cited several formulations of polyester resin, vinyl ester, coal tar epoxy, epoxy and specialty concrete as having excellent bonding characteristics to both corroded and uncorroded concrete, as well as to themselves, and also excellent resistance to sulfuric acid attack (5). It must be noted that all of the successful coating systems consisted of sand-extended resin systems (polyester, vinyl ester, epoxy and coal tar epoxy) that were applied as a three-step process (primer, sand-extended thickened coating and top coat) to a thickness of 120 - 150 mils. For instance the same product which scored an excellent rating when used as an extended sand system scored very poorly when used without the sand (reference test numbers 17 and 57 in Table 6-2.) Table 6-2 summarizes the coating systems evaluated by CSDLAC, and their performance.

When dealing with metals, consideration of coating systems must also include proper selection of primers. Two basic types of primers exist; 1) inhibitive primers and 2) barrier primers. Inhibitive primers include zinc chromate and red lead. Zinc chromate is not recommended for use in acidic or immersed environments. Red lead primers are alkaline and thus can neutralize acid agents. They also react with oils to form dense, low-permeability films. Inorganic zinc primers are very effective and an excellent choice for use in immersion service.

6.2.1.3 Chemical Conversion Coatings

Chemical conversion coatings cause a chemical reaction to occur between the coating material and the base metal such that the coating becomes an integral part of the metal.

TABLE 6-2

LOS ANGELES COUNTY SANITATION DISTRICTS COATING STUDY (5)

COATING TEST PERFORMANCE

STATUS	TEST/GENERIC TYPE	BRAND NAME	PERFORMANCE RATING EASE OF APPLICATION	PERFORMANCE RATING CORROSION RESISTANCE	PERFORMANCE RATING BONDING PERFORMANCE	COMMENTS	CUMULATIVE TOTAL
CS	17 POLYESTER	QUANTUM	1	1	1	NO PROBLEMS	3
CS	44 POLYESTER	I. E. T. SYSTEM 3	2	1	1		4
CS	38 VINYL ESTER	120 VINESTER	1	1	1	EXTENDED CURE	3
CS	37 COAL TAR EPOXY	MAINSTAY DS-4	1	1	1		3
CS	40 LINER	VINYLTHANE (PVC)	1	1	2		4
CS	28 EPOXY	CONCRESIVE 1305	1	2	1	NO PROBLEMS	4
CS	45 EPOXY	CHESTERON 798 POLYMER QUARTZ	1	2	1	CORROSION BUBBLES	4
CS	25 EPOXY	AQUATA POXY	2	1	1	SURFACE REPAIR REQ	4
TBS	53 EPOXY	I. P. I. CRYSTAL QUARTZ	1	1	1	NO PROBLEMS	3
TBS	50 EPOXY	MAGMA QUARTZ	2	1	1		4
TBS	49 EPOXY	SEMSTONE 140S	1	1	1		3
TBS	59 SPECIALTY CONCRETE	HORTONCRETE 126-6200	1	2		NO PROBLEM	3
TBS	58 SPECIALTY CONCRETE	HORTONCRETE 126-6200	2	2		NO PROBLEM	4
TBS	61 EPOXY RESIN	SAUEREISEN 210	2	1	1		
			TESTING CONTINUES				
	66 SPECIALTY CONCRETE	CHEMPRUF (NOT A COATING)				TEST CONTINUES	
	65 URETHANE FOAM & PVC LINER	ALLIED FOAM & PVC	1			TEST CONTINUES	
	64 URETHANE	ALLIED FOAM	1			TEST CONTINUES	
	63 PVC LINER	DANBY PVC-T-LOCK		1	1	TEST CONTINUES	
	62 PVC LINER	PVC-T-LOCK		1	1	TEST CONTINUES	
			FAILED SYSTEMS				
	52 URETHANE	CRANDAL SHB 1000	1	1	2	DELAMINATION	4
	42 EPOXY	FIBRE/CRETE 204	2	2	1	JOINT WEAKNESS	5
	10 URETHANE	PR 475	2	2	1	SURFACE REPAIR REQ	5
	11 SPECIALTY CONCRETE	PCM 505	1	4	1	ACID REACTION	6
	51 EPOXY	CR BARRIER	2	3	1	PINHOLES	6
	20 COAL TAR	FARBERTITE	1	4	1	ACID ATTACK	6
	21 EPOXY	IPANOL CH	1	4	1	ACID ATTACK	6
	1 URETHANE	SENOTEX 3005	2	1	3	IMP. PRIMER REQ'D.	6

TABLE 6-2 (CONT.)
LOS ANGELES COUNTY SANITATION DISTRICTS COATING STUDY (5)
COATING TEST PERFORMANCE

			PERFORMANCE RATING				
STATUS	TEST/GENERIC TYPE	BRAND NAME	EASE OF APPLICATION	CORROSION RESISTANCE	BONDING PERFORMANCE	COMMENTS	CUMULATIVE TOTAL
2	SPECIALTY CONCRETE	SILOSEAL	1	4	1	ACID REACTION	6
35	LINER	URETHYLENE LINER	1	2	3	POOR BONDING	6
6	SPECIALTY CONCRETE	THOROSEAL	1	4	1	ACID REACTION	6
3	URETHANE	ZEBRON	2	1	3	PRIMER NEEDED	6
47	URETHANE	SANCON 100	2	2	2	POOR CURING ALLOW	6
33	URETHANE	L1304-267	3	3	1	PINHOLES	7
56	EPOXY	NU-KLAD 100A	2	4	1	ACID REACTION	7
48	URETHANE	SENOTEX 3013	3	1	3	PINHOLES	7
41	EPOXY	OVERKOTE V	4	2	1	ACID REACTION	7
22	EPOXY	FOSROC EPOXY LINER	3	3	1	> 30 MILS REQ'D.	7
26	URETHANE	VIBRABOND 500	4	1	2	POOR BONDING	7
19	EPOXY	SIKAGARD 62	2	4	1	ACID REACTION	7
16	EPOXY	CONCRESIVE-1305	2	4	1	PINHOLES	7
12	SPECIALTY CONCRETE	POLYMER CONCRETE	3	3	1	ACID REACTION	7
55	COAL TAR URETHANE	BITUMASTIC COAL TAR URETHANE	3	2	3	PINHOLES	8
54	VINYLESTER	PLASITE 4300	3	3	2	ACID REACTION	8
32	URETHANE	SANCON-100	4	2	3	PINHOLES	9
14	EPOXY	SIKAGARD 61	2	4	3	ACID REACTION	9
57	POLYESTER	QUANTUM	2	4	4	PINHOLES	10
31	SILICONE	BUTEC 165-205	4	4	2	PINHOLES	10
13	SPECIALTY CONCRETE	ALL-CRETE MP		4		OFF MARKET	
29	LINER	PVC	3	1		POOR JOINTS	
34	SPECIALTY CONCRETE	ACID-PROOF CEMENT NO. 54	2	2		CEMENT POROUS	
7	EPOXY	ENGARD 460	1	4		ACID REACTION	
43	CONCRETE SEALANT	CRYSTAL-LOK	1	4		ACID REACTION	
9	URETHANE	PR 319	1	4		ACID REACTION	
39	URETHANE	ZEBRON 386/9000	4		1	PINHOLES	
30	COAL TAR EPOXY	CTE-200		4	1	ACID REACTION	
18	CONCRETE SEALANT	SINAK SEALER, S101 & S102	1	4		ACID REACTION	

TABLE 6-2 (CONT.)
LOS ANGELES COUNTY SANITATION DISTRICTS COATING STUDY (5)
COATING TEST PERFORMANCE

			PERFORMANCE RATING				
STATUS	TEST/GENERIC TYPE	BRAND NAME	EASE OF APPLICATION	CORROSION RESISTANCE	BONDING PERFORMANCE	COMMENTS	CUMULATIVE TOTAL
	8 URETHANE	PR 318	1	4		ACID REACTION	
	15 EPOXY	CONCRESIVE AEK-1513	3		3	POOR BOND	
	46 SPECIALTY CONCRETE	HORTONCRETE 126-6200	3	4		AIR POCKETS	
	36 URETHANE	GS 1490	4		3	POOR BOND	
	4 URETHANE	TORBON	4		3	PINHOLES	
	60 URETHANE	P. R. -2331	4		3	POOR BOND	
	5 URETHANE	DURATHANE	4		3	PINHOLES	
	23 EPOXY	PLASITE 5308		1		NO TEST	
	24 PHENOLIC	PHENOLINE 307		3		OFF MARKET	
	27 SPECIALTY CONCRETE	SWINDRESS BOND 110		3		ACID ATTACK-NO TEST	

NOTES FOR STATUS:

CS INDICATES THAT THE CSDLAC CURRENTLY SPECIFIES THE COATING SYSTEM.
TBS INDICATES THAT THE CSDLAC INTENDS TO SPECIFY THE COATING SYSTEM IN THE NEAR FUTURE.

NOTES FOR PERFORMANCE RATINGS:

1. NO PROBLEMS DURING APPLICATION; EXCELLENT RESISTANCE TO ACID SOLUTION; GOOD BOND TO CONCRETE SUBSTRATE.
2. SOME APPLICATION PROBLEMS, BUT NOT ATTRIBUTABLE TO MATERIAL; SOME REACTION WITH ACID, BUT NO COATING FAILURE; ADEQUATE BUT NOT TENACIOUS BOND TO CONCRETE SUBSTRATE. PROBLEMS ARE NOT SIGNIFICANT.
3. SIGNIFICANT PROBLEMS DURING APPLICATION; POOR CORROSION RESISTANCE; MATERIAL DID NOT BOND PROPERLY TO THE SUBSTRATE.
4. FAILURE AS A RESULT OF SERIOUS APPLICATION PROBLEMS; REACTION OF ACID WITH THE COATING; FAILURE OF THE COATING TO PROTECT THE CONCRETE DURING THE TEST PERIOD.

Phosphate coatings are produced by reaction of the base metal with a phosphoric acid solution containing iron phosphates and zinc, iron or manganese. These coatings are normally used to provide better adhesion of paint.

6.2.2 Linings

Linings typically consist of pre-cured polymeric materials such as polyethylene, polyvinyl chloride, polypropylene and glass-reinforced plastic. Liners generally can be supplied in either of two forms; sheet goods or thin-walled forms.

Segmented polyvinyl chloride, polyethylene, fiberglass-reinforced plastic, fiberglass-reinforced cement and interlocking polyvinyl chloride strips are all fully described in Chapter 7.

According to a study performed by the County Sanitation Districts of Los Angeles County, one polyvinyl chloride sheet liner demonstrated no reaction to acid, but the non-welded jointing systems allowed acid to seep behind the liners and corrode the concrete. Where this type of liner is to be used, the CSDLAC recommends the use of welded PVC joints, detailed construction inspection and spark testing (5).

As an alternative to mechanically anchoring liners to concrete and relying on suitable joints, the use of an acid resistant mastic that bonds the liner material to concrete can be used. This type of system was tested by CSDLAC and is now specified by the Sanitation Districts for rehabilitation projects. It has also been test applied in a gravity sewer by the Seattle Metropolitan Sewer District.

New construction or replacement allows for the use of PVC liners that are formed in place with the concrete. Proper welding of the liner joints is critical in eliminating the potential for seepage to occur between the liner and concrete. The use of PVC liners is more fully discussed in Chapter 7.

6.3 Replacement with Corrosion-Resistant Materials

Materials often found in wastewater treatment facilities and pump stations that are prone to hydrogen sulfide corrosion include cast iron, ductile iron, steel, copper, asbestos cement and concrete. Section 6.2 discussed the types of protective coatings and liners available to extend the useful life of materials subject to corrosion. However, many of these components will eventually fail or otherwise require rehabilitation or total replacement. When replacement does occur, the use of corrosion-resistant materials should be strongly considered. The use of such materials will likely increase the beneficial life of these components substantially. The following paragraphs describe the types of corrosion resistant materials available.

6.3.1 Corrosion-Resistant Metals

Several metals are available that can provide effective corrosion-resistant service. These metals range from coated materials such as are obtained by galvanizing and electroplating (see Section 6.2.1.1), to stainless steel, aluminum and more exotic metals.

6.3.1.1 Copper Alloys

Copper can be readily attacked by H_2S, which turns the surface of the metal black (copper sulfide). However, copper alloys, such as brass and bronze, can offer good protection.

Brass is a copper alloy containing from 5 to 45 percent zinc, and protects the copper by selective corrosion of the zinc. However, this leads to increased porosity and a loss of structural strength of the alloy.

Bronze can contain either tin (up to 12%), aluminum (up to 10%), or silicon (up to 4%). Because bronze does not undergo selective corrosion, it is generally stronger and harder than brass. Aluminum bronze is the most resistant to H_2S and acid attack, and silicon bronze is resistant particularly to hydrochloric and sulfuric acid, alkalies and some organic compounds.

6.3.1.2 Nickel Alloys

Nickel and nickel alloys provide superior resistance to corrosion, and are stronger and harder than copper or aluminum alloys. Depending on desired properties and corrosion resistance, nickel alloys may contain other metals such as copper, silicon, chromium, iron, and molybdenum.

6.3.1.3 Stainless Steel

Stainless steels are alloys containing over 11.5 percent chromium and possibly nickel (6 to 22 percent). They provide excellent corrosion resistance as well as resistance to organic and inorganic acids and alkalies. Stainless steels are susceptible, however, to halides, seawater and oxidizing chlorides. Stainless steels are classified by three basic crystal structures; martenistic, ferretic and austenitic.

Of the three crystalline structures, austenitic stainless steel is used in corrosive environments. More specifically, Type 304L and Type 316L are low carbon steels (less than 0.03 percent carbon) routinely used in corrosion applications. The main difference between these two stainless steel types is that Type 316L contains 2 - 3 percent each of molybdenum and nickel, and has less chromium than 304L. Type 316L is more resistant and better suited to sulfuric acid environments.

6.3.1.4 Aluminum

Aluminum is used widely in the wastewater treatment field because of its light weight, strength and resistance to hydrogen sulfide corrosion. It is not affected by methane, carbon dioxide or sulfur dioxide. However, aluminum is susceptible to galvanic corrosion, and must be physically separated from dissimilar metals and concrete. Frequently the physical separation consists of an asphaltic coating, stainless steel or neoprene washers. Aluminum is also subject to attack by acids, salts and aggressive water.

6.3.2 Corrosion-Resistant Concrete

Concrete can be rendered more resistant to sulfide corrosion attack in the following ways:

1. through the use of high alumina or silica cements in lieu of Portland cement, or
2. through the use of calcareous aggregate instead of granitic aggregate.

When cements containing aluminum are used instead of the more common calcium hydroxide, the alumina gels and coats the hydrates. The alumina does not dissolve readily until pH drops below 4.0, so a concrete mixed with high alumina cement can provide an increased level of sulfuric acid corrosion protection in those instances where the pH will not be too acidic. However, pH of concrete walls may often drop to 1.0 or 2.0 in enclosed and unventilated areas, such as sewers and enclosed tanks. High alumina cement content concrete can actually be attacked more quickly than Portland cement at these very low pH levels.

Sodium silicate has also been used as an inorganic cement substitute. These are presumed to fail under two conditions. First, the sodium, which is alkaline, reacts with acidic sulfur compounds to form sodium sulfate. Upon hydration, the cement expands and failure occurs. Secondly, when used as a coating over Portland cement concrete, microorganisms enter the porous lining and continue to attack the original concrete substrate (6).

Potassium silicate is claimed to be superior to other inorganic cements due to its resistance to acids and its resistance to spalling in the presence of sulfuric acid. Surface preparation consists of water or abrasive blasting, application of a moisture-tolerant primer (if the concrete cannot be dried sufficiently), crack repair by epoxy injection, and pH analysis of the original concrete surface by petrographic examination. pH adjustment of the concrete may be required prior to application of the new coating system (the pH of unattacked concrete should be 11 or greater). Fresh concrete can be applied to obtain a good base, and then top coated. Anchors are preferred over wire mesh for the new concrete substitute onto which two coats of a urethane-based membrane is applied. The 100% potassium silicate-bonded concrete is then usually applied by the gunite method. The urethane-based membrane wet film thickness should be in the range of 63 to 130 mils (60 to 125 mils dry), applied by airless spray at a pressure of approximately 4,000 psi. The potassium silicate cement concrete consists of a binder, a catalyst and the aggregate. Some suppliers provide the binder and catalyst combined as a powder. Because the dried potassium silicate powder is very slowly soluble in water, concrete from these one-part mixes are generally of a low strength. Application thickness is generally 1½ to 3 inches. Rate of application is on the order of 1,000 square feet per 8-hour shift, and curing time can be as short as 24 hours (when temperature is in excess of 50°F). The cities of Orlando and Jacksonville have utilized this concrete product for a period of up to 7 years in grit chambers, as has Tampa, Florida for a junction chamber (6). It should be noted that potassium silicate concrete is actually quite porous, and that the corrosion protection may be from the urethane coating rather than the concrete itself.

Changing the aggregate from granitic to calcareous can also be used as a deterrent to hydrogen sulfide corrosion by providing additional alkalinity of the concrete in order to neutralize the sulfuric acid formed.

6.3.3 Corrosion-Resistant Synthetic Liners

Synthetic materials generically include plastics, ceramics and elastomers. Many of these products are unaffected by sulfuric acid.

Plastics are identified as either thermoplastics or thermosetting plastics. Thermoplastics can be heated to a plastic state, molded, cooled, reheated and remolded. Thermoplastics are not normally used at temperatures greater than 65°C (150°F). Polyvinyl chloride, polyethylene and vinyl are all thermoplastics. Unlike thermoplastics, thermosetting plastics cannot be remolded due to the chemical reactions that occur upon initial heating. Polyesters, epoxies and phenolics are all considered thermoplastics. Some thermoplastics can be used at temperatures up to 150°C (300°F).

Fiberglass reinforce plastic (FRP) is fabricated by impregnating interwoven continuous glass filaments with a thermosetting resin, and heat curing. Typical FRP uses at wastewater treatment facilities are piping, grating and stair treads. In addition fiberglass reinforced with a thermosetting polyester or vinyl ester resin is manufactured to produce numerous corrosion-resistant, non-conductive structural shapes and sheets. These materials are actually stronger on a pound-for-pound basis than is structural steel. Uses include structural elements, railings, weirs and baffles.

Ceramics are also excellent for use in corrosive areas, but they remain brittle.

Elastomers such as neoprene, butyl, isoproprene and others are commonly used as sealants. Neoprene is resistant to oils, grease and other contaminants, and is often used at wastewater treatment facilities.

6.4 Case Studies

The following paragraphs illustrate corrective actions taken at several wastewater treatment facilities. Refer to Appendix A.2 (case studies) for more information concerning rehabilitation/replacement techniques employed at selected wastewater treatment facilities.

The Hooker's Point Wastewater Treatment Plant, located in Tampa, Florida, currently processes 54 mgd and has a design flow of 60 mgd. The facility was expanded in 1978, and a sludge dryer and pelletizer were started up in 1990. The treatment plant has experienced severe corrosion and expends significant resources to combat hydrogen sulfide corrosion, including a fine-mist scrubber installed to treat H_2S-laden air emissions at the influent junction box. The scrubber was installed at a capital cost of $1,000,000, and annual operating cost is estimated at $400,000. Table 6-3 summarizes the corrective actions taken by the City of Tampa to combat corrosion at the Hooker's Point WWTP.

The Hyperion Wastewater Treatment Plant, which serves the City of Los Angeles, California, is designed for 150 mgd through secondary treatment and 400 mgd through primary treatment. The treatment facility is approximately 40 years old and is currently undergoing massive reconstruction due to changes in regulations which have eliminated ocean sludge disposal and mandated secondary treatment. Many of the facility's unit processes are being upgraded or replaced, but severe corrosion remains evident in several areas. The corrective actions at Hyperion are summarized in Table 6-4.

The Terminal Island Wastewater Treatment Plant, which also serves the City of Los Angeles, provides secondary treatment for 30 mgd. This facility was constructed in 1935 and upgraded in 1977. Its flows and loads are 50 percent and 70 percent industrial, respectively. Similar to the Hyperion facility, most of the preliminary treatment area is covered and not easily observable. The corrective actions taken to combat corrosion at Terminal Island are summarized in Table 6-5.

TABLE 6-3

SUMMARY OF CORRECTIVE ACTIONS TO COMBAT HYDROGEN SULFIDE CORROSION AT HOOKER'S POINT WWTP

ITEM	CORRECTIVE ACTION
INFLUENT JUNCTION BOX	
Concrete walls	Plastic liner
Carbon steel parts	Replaced with stainless steel where possible
Electrical components, outlets	Covered or replaced with plastic
Aluminum parts	Replaced with fiberglass
Atmospheric H_2S	Installed scrubber
PRIMARY CLARIFIERS	
Moving parts, including scraper mechanism	Replaced with plastic
Electrical/mechanical components	Covered with corrosion-resistant materials
Concrete walls	No action yet, but considering plastic liner
SLUDGE HANDLING	
Metals	Replaced with galvanized and stainless steel
INSTRUMENTATION & CONTROLS	
Instruments	Covered
Cabinets	Purged with clean air
Control Rooms	Air conditioned
Contacts and Relays	Cleaned regularly
Transformer housings	Periodically replaced

TABLE 6-4

SUMMARY OF CORRECTIVE ACTIONS TO COMBAT HYDROGEN SULFIDE CORROSION AT HYPERION WWTP

ITEM	CORRECTIVE ACTION
HEADWORKS TANKS & CHANNELS (COVERED)	
Concrete covers and walls above waterline	Channels to be rehabilitated or replaced using PVC liners. Tanks will be coated with coal tar epoxy or other material.
Building enclosures	Negative pressure maintained by fans and discharged to the secondary process blowers.
Piping	Mostly PVC; air handling ducts are fiberglass
Electrical conduit	PVC or aluminum
PRIMARY CLARIFIERS (COVERED)	
Upper concrete walls	Grouting only (earlier epoxy coatings have failed)
Channels	Walls to be lined with PVC. Covers are aluminum plate
Steel chains	Replaced with plastic
Wood sludge rake boards	Replaced with fiberglass
INSTRUMENTATION & CONTROLS	
Field-mounted instrumentation	Purged with nitrogen
Control room atmosphere	Scrubbed, filtered and air conditioned

TABLE 6-5

SUMMARY OF CORRECTIVE ACTIONS TO COMBAT HYDROGEN SULFIDE CORROSION AT TERMINAL ISLAND WWTP

ITEM	CORRECTIVE ACTION
HEADWORKS	
Concrete walls	No action (negligible corrosion)
Metallic covers	Aluminum deck plate
Handrails	Aluminum
Conduit	Aluminum
Bar screen sheet metal	Replaced with sheet PVC
Steel bar screen frame	To be replaced with stainless steel
Building enclosures	Negative pressure maintained by suction through the secondary process blowers and discharge to aeration basins
Piping	Mostly PVC; air handling ducts are fiberglass
Electrical conduit	Aluminum or PVC
PRIMARY CLARIFIERS	
Clarifier covers	Aluminum
Influent/effluent channel cover plates	Aluminum
Steel chain	Replaced with plastic, but due to problems with chain jumping sprockets, reverting back to steel
Wood sludge rake boards	Replaced with fiberglass

TABLE 6-5 (cont.)

SUMMARY OF CORRECTIVE ACTIONS TO COMBAT HYDROGEN SULFIDE CORROSION AT TERMINAL ISLAND WWTP

ITEM	CORRECTIVE ACTION
ANAEROBIC DIGESTERS	
External gas collection pipe	Replaced with welded stainless steel
Motorized valves, copper grounding wire (bare) and elevator	Corrosion may be due to salt air
INSTRUMENTATION & CONTROLS	
Field-mounted instrumentation	Purged with nitrogen
Control room atmosphere	Scrubbed, filtered and air conditioned

6.5 References

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7. REHABILITATION OF CORRODED SEWERS

7.1 Rehabilitation and Repair Techniques

Rehabilitation of corroded sewers can be implemented by many techniques. This chapter examines each of the generic methods and provides guidance on the conditions under which each method is applicable. For each rehabilitation method, a general description is provided, and procedures and equipment are discussed. It should be noted that new techniques for sewer rehabilitation are continually being developed. While all major generic rehabilitation techniques have attempted to be included, specific proprietary systems have not been evaluated.

Table 7-1 lists common corrosion problems in sewer pipes and applicable rehabilitation method(s) for each.

7.1.1 Insertion Renewal (Sliplining)

7.1.1.1 Description

Insertion renewal, or sliplining, is used to rehabilitate sewers by pushing or pulling a flexible liner pipe of slightly smaller diameter into an existing circular pipeline and then reconnecting the service connections to the new liner. By fusing sections together during installation, the liner forms a continuous, water tight length within the existing pipe.

Pipe insertion techniques can be used to rehabilitate sewer, water and other lines that may have severe structural problems such as extensively cracked lines, lines in unstable soil conditions, deteriorated pipes in corrosive environments, and pipes with massive and destructive root intrusion problems. Advantages and disadvantages of sliplining as a method of rehabilitation can be found in Table 7-2 (1).

TABLE 7-1

SUMMARY OF APPLICABLE PIPE REHABILITATION METHODS FOR PIPE DAMAGED BY HYDROGEN SULFIDE CORROSION

Problem	Rehabilitation Method
1. Pipe is seriously damaged or collapsed	a. Excavation and replacement
2. Poor structural integrity caused by corrosion	a. Excavation and replacement b. Insertion renewal c. Some specialty concretes
3. Severe corrosion but reinforcing steel not exposed	a. Insertion renewal b. Cured-in-place inversion lining c. Excavation and replacement
4. Damaged pipes under structures, large trees, or busy streets	a. Insertion renewal b. Cured-in-place inversion lining
5. Severe corrosion in noncircular pipes	a. Cured-in-place inversion lining b. Excavation and replacement
6. Mildly deteriorated structure	a. Insertion renewal b. Cured-in-place inversion lining c. Liners d. Specialty concrete

Note: When replacement is the only feasible option, consideration of new alignment may be warranted to avoid excavation of existing utilities.

TABLE 7-2

ADVANTAGES AND DISADVANTAGES OF SLIPLINING (1)

ADVANTAGES	DISADVANTAGES
Minimal disruption to traffic and urban activities (as compared to replacement)	Possible reduction in pipe capacity, depending on wall thickness required
Minimal disturbances to other underground utilities; affects only those in the vicinity of access pits	Requires excavation of an access pit
Less costly than replacement	Not applicable to sewers with numerous curves, bends, offset joints or protruding service taps
Rapid installation	Requires obstruction removal prior to sliplining
Good protection against acid corrosion	Grouting of annular space may be required
May not require bypassing	
Wide range of pipe sizes (i.e., 3 to 144 inches)	
Can be used to rehabilitate pipelines with severe corrosion	
Stops leaks and root intrusion	

Materials frequently used to slipline sewers include polyethylene, thermoset plastic, polyvinyl chloride and ductile iron pipe.

Non pressure-rated polyethylene pipe is primarily used for sewer relining applications. PE pipe is available in sizes ranging from 4 through 48 inch diameter, and jointing is commonly by butt-fusion, though fittings can be used.

Thermoset plastic pipe, which includes reinforced thermosetting resin (RTR) and reinforced plastic mortar (RPM), is manufactured with reinforcement such as fiberglass embedded in a thermosetting resin. Thermoset plastic pipe is available in sizes ranging from 8 through 144 inches, and a number of jointing methods are available.

Polyvinyl chloride pipe is manufactured by extrusion of plastic. PVC pipe is available in sizes ranging from 4 thorough 27 inch diameter, and jointing is commonly elastomeric seal gasket with bell-and-spigot connection.

Ductile iron pipe is manufactured by adding cerium or magnesium to cast iron prior to casting. DIP is available in sizes ranging from 3 through 54 inch diameter, and various jointing methods are available. Interior and exterior coatings are available.

7.1.1.2 Procedures and Equipment

Prior to sliplining, the sewer or water main should be first be inspected by closed circuit TV to identify all obstructions such as displaced joints, crushed pipes and protruding service laterals. The inspection also should locate all service connections that will need to be connected to the new liner pipe. The pipe must be thoroughly cleaned. Proof testing the existing pipe by pulling a short piece of liner through the sewer section should be performed prior to sliplining. Sliplining generally will require excavation of an access pit from which to work from, though some sliplining techniques can operate from a manhole. Protection of sliplining access pits is critical to prevent trench collapse which could occur as a result of sewage flooding or groundwater pressure.

Sliplining is performed by either a push or a pull technique; both methods are illustrated in Figure 7-1. In the pull method a pulling head is attached to the end of the pipe. A cable is run from the termination point to the access point and is connected to the pulling head. The slipline pipe is then pulled through the existing pipe with the cable by a truck mounted winch assembly.

The push technique is similar, except a backhoe or other suitable equipment is used to push the liner through the pipe. For most insertion projects it is not necessary to eliminate the entire flow stream within the existing pipe structure. Actually, some amount of flow can assist positioning of the liner by providing a lubricant along the liner length as it moves through the deteriorated pipe structure. The insertion procedure should be timed to take advantage of cyclic periods of low flows that occur during the operation of most gravity piping systems. During the insertion process, which often takes a period of 30 minutes or less per length of pipe, the annular space between the sliplining pipe and the existing pipe can usually carry sufficient flow to maintain a safe level in the operating section of the system being rehabilitated during low flow periods (2). Sewer flow gauging and a calculation of the hydraulic capacity of the annular space should be performed to ensure that no upstream flooding will occur during the insertion process.

Once the slipline pipe has been installed in the existing deteriorated pipe, it is grouted in place. Grouting at each manhole connection is required, and grouting of the entire length of the pipe may be required if the liner cannot support loads resulting from the collapse of the original pipe. The severity of structural deterioration and anticipated hydrostatic and structural loadings must be considered in evaluating the need for grouting. Grouting provides the following advantages:

- provides structural integrity
- increases hydrostatic and structural loading capacities of the pipe

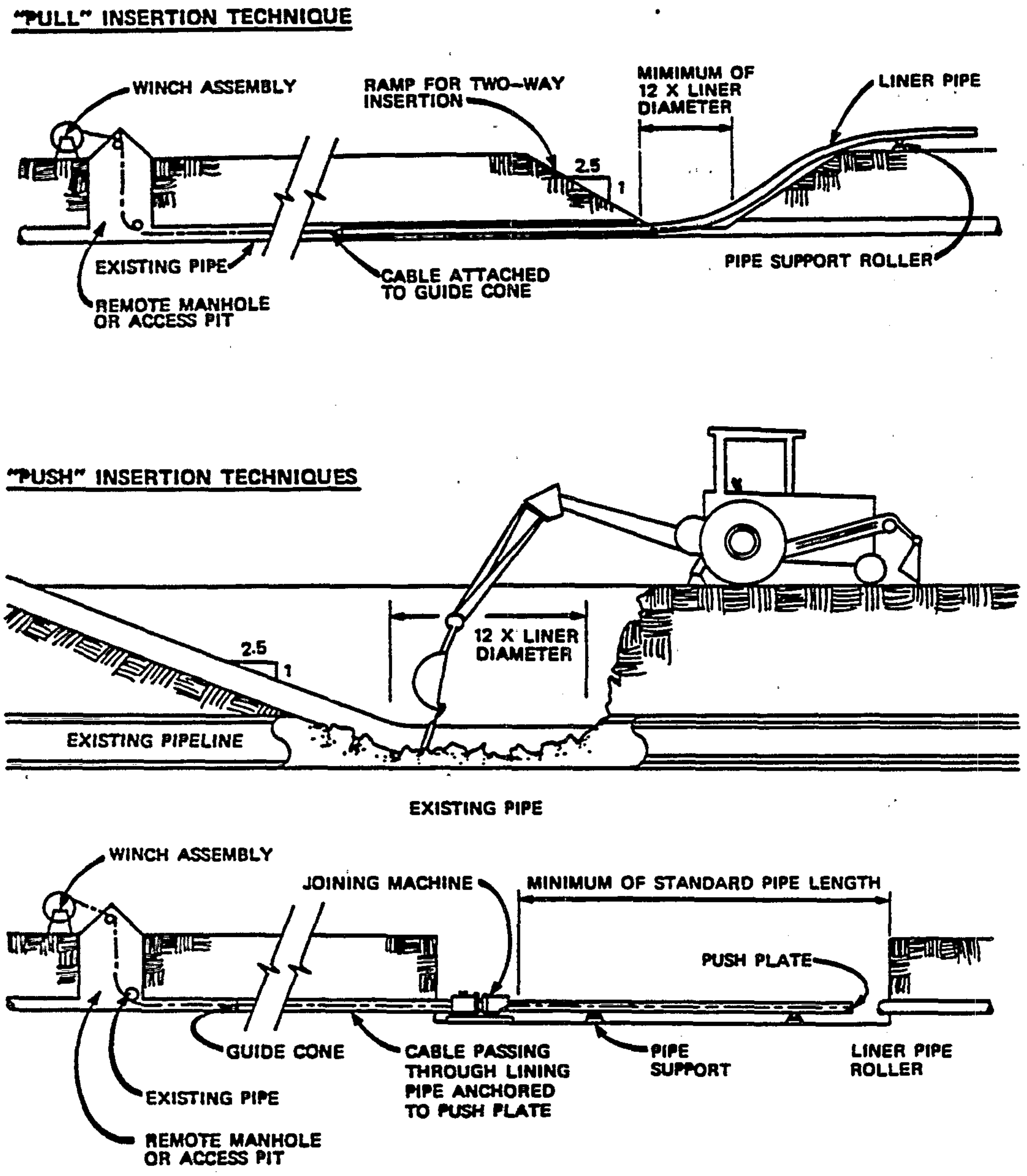

FIGURE 7-1. EXAMPLES OF BASIC SLIPLINING TECHNIQUES
(from Reference 2)

- prevents liner from moving
- locks in service connections
- extends life of pipe from uncertain to 50 years plus
- provides support to liner when cleaning

Equipment required for the insertion of the sliplining pipe are: joining equipment, pulling or pushing head, winch, rollers, proofing tool, grout tank and pump. The joining equipment is used to join segmented pipe length to a continuous pipe of desired length. This is done by aligning the two pipes together, heating the ends and butting the ends together. The pulling head is used to facilitate the pulling of the pipe into the sewer. One end of the pulling head is attached to the pipe to be pulled while the other end is attached to the pulling cable. The winch, consisting of a power operator and a pulling cable, is used to pull the pipe. The rollers are used to hold the liner in place in order to grout the annular space between the pipe and manhole connections.

7.1.2 Deformed Pipe Insertion

This technique involves use of a thermoplastic polyethylene pipe extruded as a round pipe. Using a thermochemical deforming process, the liner, which is manufactured in various wall thicknesses, is deformed into a U-shape. The deformed pipe is then pulled through the existing sewer pipe with minimal friction. Once the liner has been set in place, a patented process involving use of heat and pressure restores the liner to its original round shape for tight fit, leaving no annular space. Virtually all of the original pipe's flow capacity is restored (1)(4)(5).

The liners can be installed in continuous lengths. Lateral connections are cut from within the pipe using a video-monitored milling apparatus. The operation of inserting the liner is as follows:

- First the corroded line is cleaned, then the deformed line is pulled inside the pipe.

- The liner is cut at such a length that it can be shaped to form its own integral seal at each manhole joint or terminal.
- A thermomechanical process is used to reform the compressed liner to its original round extruded shape. This may be done with heated liquid or in combination with a thermally controlled pig.
- Once in place and properly reexpanded and flanged, the inserted liner is tested in conformity with A.P.I./D.N.V. standards.

The following advantages are offered by the use of deformed pipe insertion techniques:

- Long continuous sections are possible (lengths may range up to 1,000 feet).
- No annular spaces are formed; no grouting is required.
- Fast installation and thus minimum downtime.
- Improved hydraulic characteristics possible.
- A variety of wall thicknesses are available to suit differing needs.

Figure 7-2 indicates a typical deformed pipe insertion technique.

7.1.3 Cured-in-Place Inversion Lining

7.1.3.1 Description

Inversion lining is formed from a resin-impregnated felt tube which is inverted under pressure against the inner wall of an existing sewer and allowed to cure. The pliable nature of the resin-saturated felt prior to curing allows installation around curves, filling of cracks, bridging of gaps, and maneuvering through pipe defects. After installation, the fabric cures to form a new pipe of slightly smaller diameter, but of the same shape as the original pipe. The new pipe has no joints or seams and has a very smooth interior surface which may actually improve flow capacity despite the slight decrease in diameter (1)(2)(3)(6).

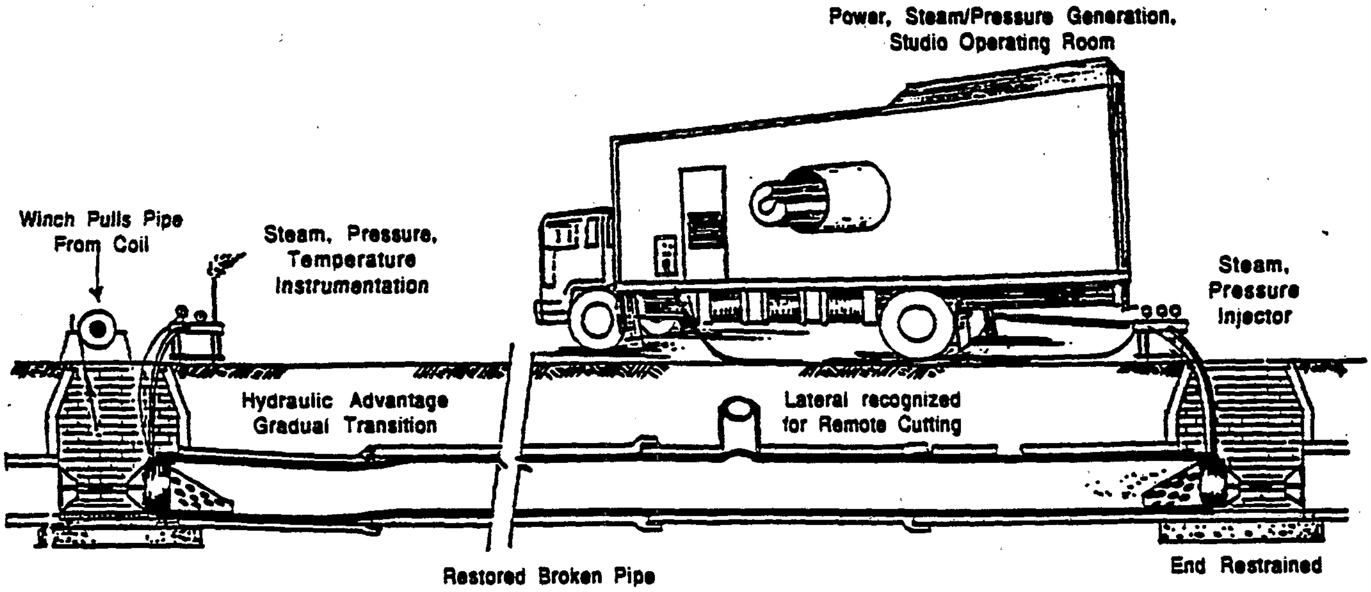

FIGURE 7-2. EXAMPLE OF DEFORMED PIPE INSERTION TECHNIQUE

Two resin types (polyester and epoxy) are widely used in this method of pipe rehabilitation. Both these resins are liquid thermosetting resins, and have excellent resistance to domestic sewage and sewage gases.

Inversion lining is successful in dealing with a number of structural problems, particularly in sewers needing minor structural reinforcement. Inversion lining can be accomplished relatively quickly and generally without excavation, though insertion pits may be required for larger pipe sizes. This method of pipeline rehabilitation is thus particularly well suited for repairing pipelines located under existing structures, large trees, or busy streets or highways where traffic disruption must be minimized. This method is also effective in correcting corrosion problems and can be used for misaligned pipelines or in pipelines with bends or non-uniform cross sections. Table 7-3 provides a summary of the advantages and disadvantages of sewer rehabilitation by cured-in-place lining (1).

7.1.3.2 Procedures and Equipment

Installation of cured-in-place inversion lining is carried out by inserting the resin impregnated fabric tube (turned inside out) into the existing pipe line. It is then cured in place through the use of heated water or air/steam. Prior to the installation of the liner, the pipeline section must be cleaned to remove loose debris, roots and solids. The installation procedures are illustrated in Figure 7-3. The pipeline segment must be isolated from the system by bypassing flows during the installation of the inversion lining. The inversion felt tube liner is usually inserted from existing manholes and valve structures, but for larger pipe sizes, insertion pits may be required. Following curing of the liner, the ends are cut and sealed. Service connections are restored by a remotely-operated cutting tool and video camera (1)(2).

Table 7-3

ADVANTAGES AND DISADVANTAGES OF CURED-IN-PLACE LINING (1)

ADVANTAGES	DISADVANTAGES
Applicable to all shapes	Bypassing required
Rapid installation	Post-installation remote camera inspection required
Minimum traffic disruption	Largest size pipe rehabilitated to date is 96"
Excavation normally not required	Maximum unrestrained pressure of 75 psi
In-line lateral reconnections can be made without excavation	Not recommended for pressure gas applications using current material and designs
Improved hydraulics	Curing time can approach or exceed 24 hours
Bridges gaps and misaligned joints	
Custom designed wall thickness	
Adds some structural integrity	
Stops leaks and root intrusion	
Pipe grouting not required	

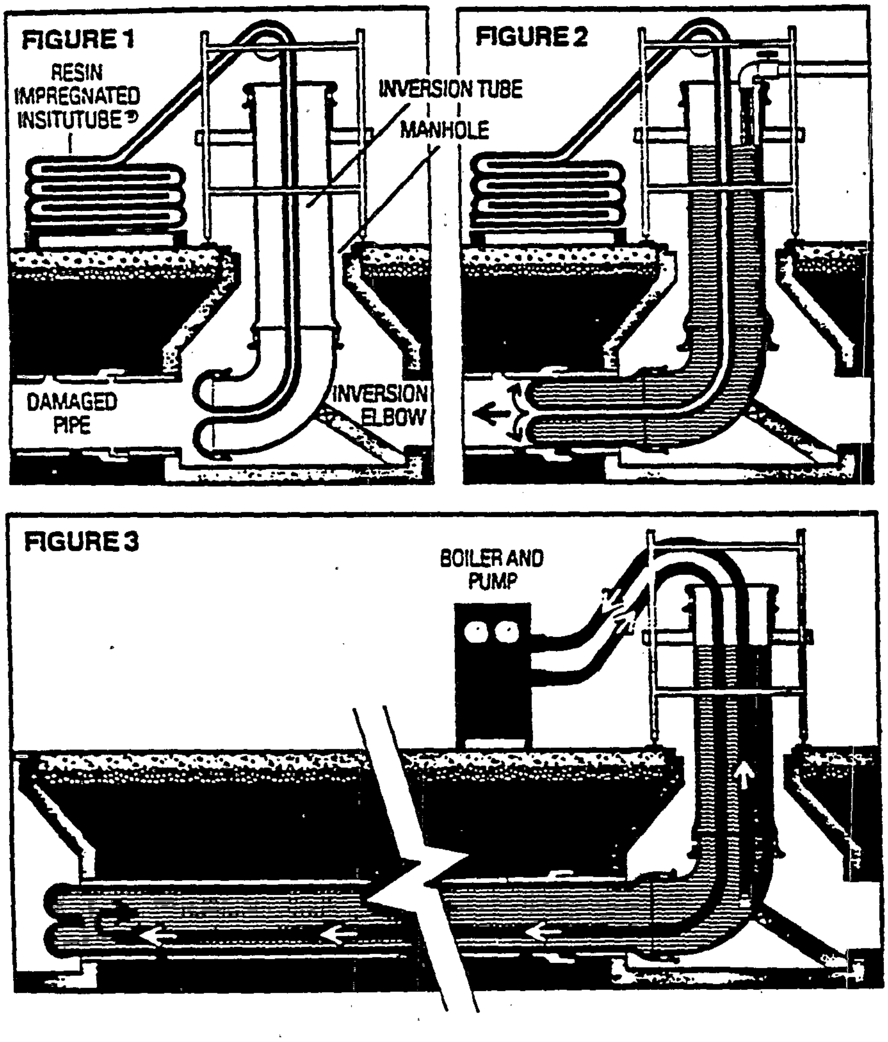

FIGURE 7-3. CURED-IN-PLACE METHOD

7.1.4 Liners

7.1.4.1 Description

Liners include prefabricated panels or flexible sheets fastened to existing structures with anchor bolts or concrete penetrating nails, continuous plastic strips which interlock to form a liner, or liners which are applied to the external portion of the pipe and then encased in concrete. The following types of liners are available for rehabilitation purposes (1)(2)(3)(6):

- Segmented PVC liners
- Segmented PE liners
- Segmented fiberglass reinforced plastic liners
- Segmented fiberglass reinforced cement liners
- Continuous interlocking PVC strips

PVC liners are manufactured from acid-resistant, rigid unplasticized PVC which has excellent resistance to acids and better hydraulic characteristics than concrete. The liners are pin-hole free, forming an effective barrier to gaseous penetration. PE liners are also similar to PVC liners but are made of polyethylene resins. Fiberglass reinforced plastic liners consist of a composite of fiberglass and acid-resistant resin. The resins are specified according to the degree of acid resistance required. Polyethylene liners are tough, rigid, acid-resistant, smooth and relatively inexpensive, and are manufactured in a wide range of wall thicknesses.

A relatively new development in liner technology for small diameter (<30 inch) pipe involves use of a winding machine to interlock continuous PVC strips into a circular tube. The winding machine is positioned in a manhole or other access point and the tube is inserted directly into the pipe. The annular space is then grouted.

Liners do not provide any structural support but they provide an adequate corrosion barrier and smooth lining for structurally sound sewers. These liners have little absorption capability and no apparent permeability. These types of liners can be used in non-circular sewers and can be segmented to fit the diameter required. Advantages and disadvantages of internal liners as a sewer rehabilitation technique are listed in Table 7-4 (1).

7.1.4.2 Procedures and Equipment

After a thorough line cleaning and dewatering, segmented liners are installed in four foot lengths which overlap at the joints. The flanges on the segments may be predrilled for screws or concrete nails. Space is allowed between the existing surface and the liner for grouting. Joints are coated with an adhesive, and sealed with an acid resistant resin. After all the panels are set in place, the entire section is cement pressure grouted in place to prevent sagging and deformation.

Another lining technique involves excavation to the damaged pipe, application of external PVC sheets around that portion of the pipe above the waterline, and encasement of the liner and upper portions of pipe in concrete. This approach allows the existing pipe to remain in service during rehabilitation. However, excavation requirements may be significant.

Installation of strip-type liners requires a manhole to accommodate an access pit that would fit the special winding machine that joins a male and female PVC strip within the access pit to form the liner pipe. Another liner installation method uses an acid resistant mastic to fasten the sheets directly to the sewer concrete surface. This technique does not require grouting but requires through cleaning prior to installation (4)(5).

TABLE 7-4

ADVANTAGES AND DISADVANTAGES OF INTERNAL LINERS (1)

ADVANTAGES	DISADVANTAGES
Material cost inexpensive	Applicable only to man entry size sewers (i.e., 2.5 feet or greater)
Linear materials have very good acid resistance	Susceptible to leakage due to number of joints
No disruptions to traffic as installation is performed entirely in-line	Timely to install. Thus total project cost maybe uneconomical because of installation
Smooth surfaces provide good hydraulics	Prolonged bypass required
	Surface preparation required
	PE can crack in areas of turbulent flow

7.1.5 Specialty Concrete

7.1.5.1 Description

Specialty concretes containing additives such as potassium silicate have shown greater resistance to acidic attack on sewer pipes and manhole structures than standard concrete mixes. Specialty concrete is used to repair deteriorated concrete pipes and structures by applying an acid resistant coating over the original surface. Concretes containing potassium silicate are unique in that their matrix is not formed by a hydration reaction. Rather, they are the result of the reaction of an acid reagent with an alkaline solution of a ceramic polymer of potassium silicate (7). Specialty cements can resist attack by many substances like mineral salts, mild solutions of organic and mineral acids, sugar solutions, fats and oils.

Applicability of specialty concrete depends on the degree of corrosion-related deterioration and the structural integrity of the unit in question. Thin film specialty concrete is applicable to mildly deteriorated pipes or structure, whereas an elastic membrane concrete system is applicable to all cases. After curing, the specialty concrete bonds firmly to the original surface. The new acid-resistant layer, if applied and cured properly, extends the useful life of the structure. Advantages and disadvantages of specialty concretes are listed in Table 7-5 (1).

7.1.5.2 Procedures and Equipment

Specialty concretes are available in three types: cement mortar, shotcrete, and cast concrete. These are briefly described below (2)(6).

Acid resistant mortars have been used in industries as linings in tanks or as mortar bricks.

TABLE 7-5

ADVANTAGES AND DISADVANTAGES OF SPECIALTY CONCRETES (1)

ADVANTAGES	DISADVANTAGES
Mortar Lining	
Minimal service interruption	Excavation required for sharp bends or curves
Improved structural integrity	Bypass required
Applicable for wide range of pipe sizes	Extensive surface preparation required
May improve flow capacity	May not provide adequate corrosion resistance
Shotcrete	
Minimal excavation required.	Requires complete diversion of flow and interruption of service
Can restore structural integrity to a pipe that might otherwise require replacement	Extensive surface preparation required
Minimum traffic interruptions	Extended downtime period of 3 to 7 days or longer required for cleaning, application, and curing
Applicable to all shapes of man-entry size pipes	Some reduction in hydraulic capacity
	Limited to man-entry size structures
	May not provide adequate corrosion resistance

TABLE 7-5 (cont.)

ADVANTAGES AND DISADVANTAGES OF SPECIALTY CONCRETES

ADVANTAGES	DISADVANTAGES
Cast Concrete	
Established procedure	Surface preparation required
Simple to design	Bypass required
Applicable to all shapes of pipes	Seldom applicable to pipes less than 48 inches in diameter
	May not provide adequate corrosion resistance

Development of mechanical in-line application methods (centrifugal and mandrel) has established mortar lining as a successful and viable rehabilitation technique for sewer lines, manholes and other structures. Mortar lining is applied using a centrifugal lining machine. The machine has a revolving, mortar-dispensing head with trowels on the back to smooth the mortar immediately after application. A variable speed winch pulls the lining machine by its supply hose. Reinforcement can also be added to the mortar with a reinforcing spiral-wound rod. The reinforcing rod is inserted into the fresh mortar and a second coat is applied over it. For man entry structures the mortar can be applied manually with a trowel.

Shotcrete is used in man entry size sewers (30 inches or greater) and manholes. Prior to shotcreting, reinforcing steel is set into place. The shotcrete lining machine is self propelled and controlled by a person riding it. An electrically driven supply cart conveys mortar from the access hole to the feeder, which is attached to the lining machine. The dry cement and aggregate is mixed with water in a specially designed spray nozzle, and the resulting mixture is shot into place under pressure. Curing occurs under moist conditions for the first 24 hours and an additional six days at a temperature above 40°F.

Cast concretes such as potassium silicate are bonded, cast or hand placed structural concretes. They typically have half the in-place density, or strength value, of shotcrete. Solids to liquid mix ratios are generally 2:1, similar to cement mortar.

Cast concrete is placed over prefabricated or custom built interior pipe forms that can be removed and reused section by section. Reinforcing steel is added between the original surface and the form, setting within the cured thickness.

Each of the three application techniques require prior cleaning to remove oils, greases, foreign objects, and loose materials, as well as sewage bypass during application and initial curing.

7.1.6 Coatings

7.1.6.1 Description

Coatings include a myriad of proprietary materials such as coal tar epoxy, concrete sealers, epoxy, polyester, silicone, urethane, and vinylester. These materials, can be applied by spray machine or brush to concrete surfaces. They are intended to form an acid resistant layer that protects the substrate concrete from corrosion. Coatings have been applied to sewer pipes and manholes since the 1960's, with mixed success. The inconsistency of success is largely due to the specification of coating materials based on manufacturer claims without actual field testing (8). As a result, engineers are recommending standard field testing of new products prior to their inclusion in specifications. Some of the advantages and disadvantages associated with the use of coatings are listed in Table 7-6 (1). Further discussions of coatings as a means of preventing hydrogen sulfide corrosion is found in Section 6.2.

7.1.6.2 Procedures and Equipment

Application of coatings usually includes the following steps:

1. Bypassing of sewage
2. Preparation and cleaning of concrete surface
3. Allowing concrete surface to dry
4. Application of coating by brush or spray
5. Allowing the coating to cure
6. Resuming sewage flow

Most coatings can be brush or spray applied. Spray application requires pressures of up to 3,000 psi, which is double the pressure used for conventional airless spraying. Spraying is excellent for coating uneven surfaces and is much faster than brush application methods for some products.

TABLE 7-6

ADVANTAGES AND DISADVANTAGES OF COATINGS

ADVANTAGES	DISADVANTAGES
Economical	Applicable only to man-entry sewers and manholes
No disruption to traffic or other utilities - work is performed in-line	Bypassing required
	Application difficulties - pinholes, blowholes
Most are fast curing, some cure in less than one hour	Poor bonding to vertical or overhead surfaces
Quick to apply	Surface preparation required
Can be applied to uneven surfaces	Contractor inexperience with products
	Surface repairs often required prior to application
	Developing technology, with history of failure under corrosive conditions

7.2 Approach to Selecting a Rehabilitation Technique

Selection of a proper sewer rehabilitation technique is very important for the successful rehabilitation of corroded sewers. The methods employed for repairing or rehabilitating a corroded or failing pipe are contingent upon several parameters. The type of application or service also has an impact on procedures and/or methodology employed in doing the repair. The correct interpretation of the cause of the problem is imperative. Some of the base parameters that must be considered in selecting the right approach for the sewer rehabilitation program are listed below and in Table 7-7 (9):

Site Conditions

- Location

  State roads, arterial roads, or similar high volume thoroughfares frequently have construction permit time restrictions and stringent restoration requirements. These conditions favor trenchless, short term reconstruction techniques such as cured-in-place and other lining systems using existing manhole access. Backyard locations frequently require techniques that utilize remote reopening of lateral connections due to inaccessibility for excavation equipment.

- Surface Cover

  High costs associated with paving restoration favor trenchless techniques. Rigid pavement replacement becomes even more cost prohibitive. In contrast, pipes in the shoulder of roads or turf covered rights of way tend to minimize potential cost savings of trenchless techniques.

Pipe Condition

- Diameter

  In their current state of development, some technologies are applicable for only a limited range of diameters. Knowing these limitations allows for the proper selection of method and specifications for the scope of work. Policy

TABLE 7-7

FACTORS TO EVALUATE FOR SELECTION OF REHABILITATION METHOD (6)

TANGIBLE	INTANGIBLE
Inspection	Noise
Engineering	Dust - Dirt
Rights-of-way	Bus Rerouting
Easements	Parking
Other Utilities	Pedestrian Inconvenience
Business Cost	Road Settlement & Potholes
Government Costs	Bidding Environment
Construction Time	Safety (Pedestrians and Auto)
Construction Cost	Road Surface Replacement
Business Disruption	City Reputation
Mobilization	Traffic Inconvenience
O & M Savings	Complaints
Detour Costs	Liability
Flow Bypassing Cost	
As-Built Drawings	
Existing Mapping	
Rehabilitation Options	
Service Laterals	
Dewatering Cost	
Material Storage	

and technical decisions can also pre-determine allowable reconstruction techniques. For instance, it may be preferable to upsize deteriorated 6" sewers to 8" sewers for future maintenance and inspection. Likewise, sliplining techniques may also be eliminated from 6", 8", and 10" sewers due to hydraulic and access consideration.

- Pipe Conditions

  Severely damaged pipe or pipes with protruding connections may require significant line preparation (excavation), thus minimizing the economic advantages of trenchless methods. This has little to no impact on techniques where excavation is already required. Areas of soil voids can be a concern where adequate soil support is required for proper performance of flexible pipe. Slope, alignment or offsets also have an impact.
- Adjacent Utilities

  Minimum clearance between water, sewer and/or gas pipes may rule out sewer replacement or encasement in concrete.

Rehabilitation Design Life

- Pipeline insertion with materials that are also used for replacement pipes should last as long as a new pipe installation, and perhaps longer because the old pipeline soil environment has usually stabilized.
- Cured-in-place-pipe should last as long or longer than new pipe when the resin characteristics have been properly identified and utilized in the design.
- Procedures that coat the pipe, such as cement mortar lining, cannot be expected to last as long as a new pipe but can have a significant useful life when the design compensates for the corrosive conditions in the pipe.

These are some of the criteria and conditions to be evaluated in selecting an approach to identify appropriate reconstruction methods. The final objective is to select a method which appropriately addresses the problems in a cost-effective manner for the life of the facilities.

Appendix A.1 includes Case Studies which describe rehabilitation/replacement techniques employed in wastewater collection systems.

7.3 References

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APPENDIX A

CASE STUDIES

A.1 Sewer Systems
A.2 Wastewater Treatment
Plants and Pump Stations

CASE STUDIES

Several wastewater collection, conveyance and treatment systems were visited to document the location, nature and extent of hydrogen sulfide corrosion. These facilities were pre-selected based on earlier surveys conducted by the Water Pollution Control Federation and County Sanitation Districts of Los Angeles County, both in 1984, and a 1987 survey conducted by the Association of Metropolitan Sewerage Authorities. Of the 131 candidate cities compiled, 66 reported sewer corrosion problems. From this, those communities showing the greatest potential for significant corrosion problems were selected and visited. The following sections summarize the information thus obtained.

A.1 Sewer Systems

Eight cities were visited to gather specific information regarding the extent of sewer corrosion. High-rate corrosion was observed in six of these cities (Charlotte, NC and Milwaukee, WI did not). A summary of the conditions observed in each city is listed in Table A-1.

A.1.1 Albuquerque, New Mexico

The City of Albuquerque maintains approximately 1,400 miles of sewer which serve approximately 450,000 people and transport an average of 49 million gallons per day (mgd) of wastewater to the city's treatment facility. Separate storm sewers are used throughout most of the city, but some combined systems do exist.

Albuquerque experiences 90 to 100 collapses per year that are attributed to hydrogen sulfide corrosion in its approximately 400 miles of 8-inch-diameter concrete pipe. These collapses are mostly in residential areas, and each typically involves two to four pipe sections (20 feet). The problem of pipe collapse is widespread in the city, but seems concentrated in North Valley, an older part of town that has the most concrete pipe, and in pipe 40 to 60 years old. The rest of the collectors are mostly clay pipe.

Table A-1

SELECTED INFORMATION FROM SITE VISITS

City and State	Sewer Age (years)	Sewer Diameter (inches)	Surface pH						Estimated Concrete Loss (inches)	Estimated Corrosion Rate (inches /year)	Corrosion Status
			Upstream		Downstream		Manhole				
			Crown (s.u.)	Wall (s.u.)	Crown (s.u.)	Wall (s.u.)	Wall (s.u.)	Roof (s.u.)			
Albuquerque, NM											
Arno	--	72	3	3	2.5	2.5	5.0	3.0	1	--	Severe
Marquette Ave. and Edith St.	--	54	--	--	--	--	--	--	--	--	--
Iron Ave. and 14th St.	--	60	4	--	4	--	--	--	2	--	Severe
Coors Blvd. and Churchill Rd.	25	30 in, 36 out	--	--	--	--	2.0	1.0	1	0.04	Severe
Atrisco Dr.	7	54 PVC	5	--	2	--	1.0	--	1 (MH)	0.14	Severe
Rossmoor Rd.	32	78	--	--	--	--	4.0	2.5	0-0.25	<0.01	Negligible
Baton Rouge, LA											
P.S. No. 59	27	NA	NA	NA	NA	NA	6.0	6.0	0.25-0.50	0.01-0.02	Shallow
Front St. and North St.	≥30	30	4.5	6.0	4.0	6.0	4.5	--	0.25-0.50	<0.02	Shallow
Devall St. and Blount St.	≥30	20 in, 42 out	2.5	2.5	5.0	5.5	2.0	--	1.0-1.5	<0.05	Severe
Harding St. and Georgia St.	≥30	30 in, 36 out	6.0	6.0	5.5	6.0	6.0	--	0.25-0.50	<0.02	Shallow
Winbourne Ave. and E. Brookstone Dr.	≥30	36	5.0	5.0	6.0	--	6.0	--	1.0-1.5	<0.05	Severe
E. Contour and S. Contour	≥30	54	3.5	--	2.5	--	--	4.0	0.25-0.50	<0.02	Shallow
Starring Lane	≥30	60	2.5	--	5.0	--	3.0	3.5	0.5-1.0	<0.03	Severe
Boise, ID											
Protest and Federal	14	21	--	--	--	--	--	--	1.0-2.0	0.14-0.28	Severe
Warm Springs and Elm	>30	10 VC	4.0	--	3.0	--	2.0	--	1.0-2.0 (MH)	<0.06	Severe
Warm Springs and N. Straugham	≥30	10 PVC	4.0	--	3.0	--	5.0	--	0 (MH)	Brick MH	NA
Bruce and Jefferson/Bannock	--	--	6.5	--	6.5	--	--	--	NA	Lined MH	NA
North Gary and Baron	12	--	6.0	--	6.0	--	1.0	--	0.5-1.0	0.04-0.08	Severe
Bluebird and Gary	12	--	3.0	--	3.0	--	1.0	--	0.5-1.0	0.04-0.08	Severe
Glenwood and State	12	--	--	--	--	--	3.0	--	--	--	Severe
Glenwood and Chindon	12	--	--	--	--	--	--	--	1.0-1.5	0.05-0.1	Severe

Table A-1 (cont.)

City and State	Sewer Age (years)	Sewer Diameter (inches)	Surface pH						Estimated Concrete Loss (inches)	Estimated Corrosion Rate (inches /year)	Corrosion Status
			Upstream		Downstream		Manhole				
			Crown (s.u.)	Wall (s.u.)	Crown (s.u.)	Wall (s.u.)	Wall (s.u.)	Roof (s.u.)			
Casper, WY											
K Street	29	36	5.0	5.0	4.0	5.0	3.0	--	1.0-1.5	0.04-0.08	Severe
G and Center St.	7	48	--	--	--	--	2.0		--	--	Shallow
801 W. Yellowstone	7	48	4.0	5.0	3.0	--	2.0	--	0-0.25	0.01-0.04	Shallow
Fairgrounds Road	7	36	5.0	5.0	5.0	5.0	6.0	--	0-0.25	0.01-0.04	Shallow
Midway Drive	7	30	6.0	6.0	6.0	6.0	1.0	--	0-0.25	0.01-0.04	Shallow
Mills Cut-Off Road	7	30	5.0	5.0	5.0	5.0	5.0	--	0-0.12	0.01-0.02	Shallow
Aster and Daffodil	7	21 in, 24 out	6.0	--	6.0	--	6.0	--	0-0.12	0.01-0.02	Shallow
Charlotte, NC											
Clanton St. at I. Creek	--	36	6.0	6.0	6.0	6.0	6.0	--	--	--	Absent
Remount St.	--	36	6.0	6.0	6.0	6.0	6.0	--	0-0.12	--	Shallow
Freedom Dr. and Thrift Rd.	--	36	6.0	6.0	6.0	6.0	6.0	--	--	--	Absent
E. 12th St. and Meyers	--	30	6.0	6.0	6.0	6.0	6.0	--	--	--	Absent
Davidson and E. 22nd	--	30	6.0	6.0	6.0	6.0	6.0	--	--	--	Could not observe
Old Providence Rd. near Sharonview	--	42	5.0	5.0	4.5	5.0	6.0	--	0-0.25	--	Shallow
Arborway near Sedley Road	--	24	6.0	6.0	6.0	6.0	6.0	--	--	--	Absent
Park Road and Moncure	--	54	6.0	6.0	6.0	6.0	6.0	--	--	--	Absent
Old Nations Ford near Ervin Lane	--	54	6.0	6.0	6.0	6.0	6.0	--	--	--	Absent
Granite St. near Continental Blvd.	--	21	6.0	6.0	6.0	6.0	6.0	--	0-0.12	--	Shallow
Fort Worth, TX											
Rosedale St.	>30	36	6.0	6.0	6.0	6.0	--	--	2.0-3.0	<0.1	Severe
Kimbo St.	31	12	5.0	--	5.0	--	5.0	--	--	--	--
Kimbo St.	31	8	6.0	--	6.0	--	4.0	6.0	1.0	0.03	Severe (MH)
Pharr St.	31	54	4.0	--	--	--	4.0	--	0.75	0.02	Shallow
Bomar St.	65	54	6.0	--	6.0	--	6.0	--	2.0-4.0	0.03-0.06	Severe

Table A-1 (cont.)

City and State	Sewer Age (years)	Sewer Diameter (inches)	Surface pH Upstream Crown (s.u.)	Surface pH Upstream Wall (s.u.)	Surface pH Downstream Crown (s.u.)	Surface pH Downstream Wall (s.u.)	Surface pH Manhole Wall (s.u.)	Surface pH Manhole Roof (s.u.)	Estimated Concrete Loss (inches)	Estimated Corrosion Rate (inches /year)	Corrosion Status
Milwaukee, WI											
Hampton and 32nd	--	36	--	--	--	--	6.5	--	--	--	Absent
Lydell and Chateau	--	42	6.5	6.5	6.5	6.5	6.5	--	--	--	Absent
Greentree Rd. Pump Station	5	72 in, FM out	6.5	6.5	6.5	6.5	6.5	--	--	--	Absent
Vienna St.	--	60	6.5	6.5	6.5	6.5	6.5	--	--	--	Absent
N. Water St. and Marshall	--	36	--	--	--	--	--	--	--	--	Absent
N. Water St. and Pierson	--	36	6.5	--	6.5	--	6.5	--	--	--	Could not observe
W. Florida St. and Forth St.	--	54	--	--	--	--	--	--	--	--	Could not observe
Barclay and Madison	--	60	--	--	6.0	--	--	--	--	--	Absent
35th and Kinnickinnic	50	36	6.0	--	3.5	--	6.0	--	1	0.02	Severe
116th and Oklahoma	--	48	6.5	6.5	6.5	6.5	6.5	--	--	--	Absent
Seattle, WA											
E. Marginal Way and 112th St.	24	2x12 in, 42 out	1.0	3.0	2.0	2.0	2.0	3.0	1	0.04	Severe
W. 15th Ave. and W. Raye St.	≥20	2x30 in, 96 out	--	--	--	--	2.5	1.0	1.5	<0.08	Severe
15 Ave. NW and 188th St. NW	--	15 in, 18 out	1.0	--	--	--	6.0	1.0	0.25-0.50	--	Shallow
NE Union Hill and Avondale	14	54	--	--	--	--	3.0	--	0-0.25	0.01-0.02	Shallow
Hollywood PS Disc. Struc.	15	--	--	--	--	--	--	--	0.25-0.50	0.02-0.04	Shallow (MH)

Corrosion seems to be worst at locations where a force main discharges to a manhole, at lift stations in gravity sewers (the city is beginning to use polyvinyl chloride [PVC] liners at those locations), near interceptors where hydrogen sulfide moves back into laterals, and at locations midway between manholes. Albuquerque does not have much industrial discharge, and pipe failures are not related to the presence of industrial discharges. There are only about three small electroplaters in the area.

In the past, Albuquerque has not had a formal program to identify corrosion. The city now has a television inspection program for small-diameter sewers (8 inches). The city replaces about 18,000 feet per year of 8- to 10-inch pipe. The goal is to replace 30,000 feet per year. The city has replaced up to 12-inch concrete lines with clay or PVC to prevent further corrosion. A total of about 40 miles of mostly 8-inch-diameter pipe has been sliplined since 1978.

Albuquerque experiences a summertime odor problem, and injects chlorine gas and hydrogen peroxide at several locations for odor control during the summer. Untreated wastewater has had total sulfide concentration of up to 4.3 mg/l. The city will be switching some of the chlorine units to hydrogen peroxide in the future, because of longer lasting effects and safety concerns.

Sewers 24 inches or less in diameter are cleaned at intervals ranging from three months to two years. Larger sewers are not cleaned.

Corrosion at the wastewater treatment facility is limited primarily to metal components. Ventilation is used to help control corrosion inside the treatment buildings.

The city identified six sites scattered throughout the area to exemplify the corrosion problem in Albuquerque: Arno and Wesmeco streets; Marquette Avenue and Edith Street; Iron and 14th streets; Coors Boulevard and Churchill Road; Atrisco Street; and Rossmoor Street.

An example of high-rate corrosion exists at the Atrisco Street site. The site is seven years old and near the upstream end of the system. The slope in this reach of pipe is very flat, and sewage velocity was estimated to be 0.5 feet per second (fps). The manhole at this site was installed with a bituminous coating that has separated almost entirely from the concrete. In seven years, the concrete on the walls and soffit of the manhole has corroded up to an estimated depth of 1.0 inch. The inlet and outlet pipes at this manhole are PVC-lined and in good condition. Measurements of pH on the manhole and pipe walls ranged from 1 to 5.

Three other sites (i.e., Arno and Wesmeco streets, Iron and 14th streets, and Coors and Churchill streets) have experienced severe corrosion. Measurements of pH on the walls of manholes and pipe ranged from 2 to 5 at Arno Street, and from 1 to 2 at Coors Street, and were 4 at Iron Street. Depth of friable concrete or corrosion product ranged from 0.50 to 2 inches. However, the pipe and manholes at these sites are considerably older than the Atrisco Street site, reflecting a lower rate of corrosion over the life of the installation. The current rate of corrosion at these sites cannot be determined from available information.

The manhole at Marquette Avenue and Edith Street has experienced some corrosion; however, manhole access problems prevented quantification. The flow in this manhole is turbulent. The Rossmoor Street site is not corroded badly, although pH ranged from 2.5 to 4 at this site.

Except for the Marquette Avenue and Edith Street site, release of hydrogen sulfide gas is not believed to be accelerated by turbulence or drops at the Albuquerque sites. Long detention times, flat slopes, and warm sewage temperatures are thought to promote hydrogen sulfide corrosion of concrete system-wide in Albuquerque, as reflected by low pH readings at all sites.

A.1.2 Baton Rouge, Louisiana

The City of Baton Rouge maintains approximately 250 miles of sewer which transport an average of 36 mgd of wastewater to the city's three treatment facilities. The sewer system serves the entire East Baton Rouge Parish except for two small communities. The system serves 375,000 people. Baton Rouge officials estimate that they have approximately 75 miles of unlined reinforced concrete pipe larger than 24 inches in diameter.

Industry contributes less than 5 percent of the total sewered flow. The major industries, including a large oil refinery, treat their own waste and do not discharge industrial effluent to the sewers. Those industries that do discharge to the Baton Rouge system are generally in compliance with the established pretreatment program. Industry is not concentrated in any one area of the system, and city engineers do not correlate corrosion in their system with industrial discharge.

The Baton Rouge sewer system is completely separate. Corrosion of concrete pipe is system-wide. Baton Rouge experienced its first sulfide-related pipe collapse about five years ago. This collapse was the first indication to the city of the severity of its corrosion problem. A consultant's report to the city on preventative maintenance of the system made reference to odor control, but did not focus on corrosion. The city did try chlorine addition in the mid-1970s, but abandoned the program in less than one year because of high costs. The city does some television inspection of the system, but does not have a system-wide hydrogen sulfide corrosion prevention program.

The city has experienced multiple problems in some pipe reaches. Repairs made with fiberglass or plastic pipe appear to be holding up well; however, one repair done with concrete pipe experienced corrosion and needed subsequent replacement. Baton Rouge acknowledges that turbulent flow conditions due to changes in grade or direction, pump station discharges, or drop connections are usually prevalent at problem areas.

Baton Rouge selected eight sites for EPA to observe: a pump station, the Central Treatment Plant, and six manholes located throughout the sewer system (two in the north subsystem, one in the central subsystem, and three in the south subsystem). The sites ranged in location from one within approximately 1 mile of a treatment plant and 10 miles from the upstream end of a reach, to one located near the upstream end of a reach. Corrosion was observed at each site, with varying degrees of severity. All sites visited were constructed in the early 1960s. Pipe slopes ranged from 0.003 ft/ft to 0.00015 ft/ft.

Pump Station No. 59, a 27-year-old structure, which is located 1 mile upstream from the Central Treatment Plant and collects wastewater from about 10 miles upstream, was the first site visited. A pH of 6 was measured on the wet well walls; shallow corrosion, 0.25 to 0.5 inches deep, was observed. The wet well often surcharges, washing the walls.

The Central Treatment Plant had shallow corrosion of some concrete structures. The force main discharge structure at the plant headworks was corroded, and aggregate was exposed in both the primary clarifier influent and effluent channels. Some corrosion of metal had also occurred at the plant headworks. A 0.6 parts per million (ppm) total sulfide content was measured in wastewater at the plant headworks. Plant influent pH was 6.

The first manhole visited is located at Front and North streets in the Central District, about 0.75 miles downstream of a pump station and within 1 mile of the Central Treatment Plant. Measurements of pH in the manhole and the 30-inch-diameter pipe ranged from 4 to 6. Large aggregate, indicating up to 0.5 inches of pipe loss, was visible in the pipes above normal water line. Flow at this location was turbulent due to the pump station upstream, a change in slope about 100 feet downstream, and a 12-inch-diameter inlet with to 2- to 3-foot drop. The wastewater had a trace of sulfide and pH of 6.

The next two sites are in the North District: Devall Lane off Blount Road, and Georgia Street at Harding Boulevard. The Devall Lane site is directly downstream of a pump station, and flow is made more turbulent by a 1.5-foot drop across the manhole. The site is located at the midpoint of a 12-mile-long drainage area. A total sulfide concentration of 0.05 mg/l and a pH of 6 were measured in the wastewater. Pipe surface pH measurements ranged from 2 to 5.5. The pipe at this location was severely corroded above the normal water surface (during pump discharge). Some mortar is missing between the bricks in the manhole and some bricks were observed on the floor of the downstream pipe. Observations revealed that as much as 1.5 inches of concrete may be corroded.

The Georgia Street site is in the upstream third of the same drainage area. The wastewater had a sulfide concentration of 0.08 mg/l and pH of 6.5. Pipe pH measurements ranged from 5.5 to 6. Although this site is also less than 0.25 miles downstream of a pump station, pipe corrosion was estimated to be minor. Only small aggregate was exposed, indicating 0.25 to 0.50 inches of concrete loss. Two drop pipes enter this manhole, and the pipe changes direction about 100 feet downstream.

The final three sites visited are in the South District: Winbourne Street at East Brookstown Drive, East Contour Drive, and Staring Lane. The Winbourne Street site had a wastewater pH of 7 and sulfide of 0.17 ppm. Pipe surface pH measurements ranged from 5 to 6. The 36-inch pipe at this location is corroded severely and corrugations were visible at reinforcing steel locations. There is a 2-foot drop across the manhole. Winbourne Street is located near the upstream end of a 15-mile-long drainage reach.

The Contour Drive and Staring Lane sites are on the same 54-inch pipe in the middle and near the downstream end of the reach, respectively. Wastewater sulfide content was 1.1 ppm at the Contour Drive site; wastewater pH averaged 6 at the two sites. Pipe surface pH measurements were between 2.5 and 4 at the Contour site, and 2.5 and 5 at Staring Lane. Corrosion at these sites was limited to about 0.50 to 1 inch of concrete loss, exposing only the first layer of aggregate.

Hydrogen sulfide gas levels of 3 to 4 ppm were measured at the Contour Drive site. The Staring Lane site is just downstream from a 36-inch-diameter force main terminus. In addition, the downstream pipe at the Staring Lane site had a broken invert near the manhole, which has created a backwater condition and turbulence at the manhole.

A.1.3 Boise, Idaho

The City of Boise maintains approximately 325 miles of sewer which transport an average of 24 mgd of wastewater to the city's three treatment facilities. Boise provides sewer service to three sewer districts and to Garden City. Boise has recognized a hydrogen sulfide corrosion problem in its system since 1983. Concrete sewers and manholes in at least four areas have experienced severe corrosion. Some of their most seriously damaged manholes have been coated recently with materials to resist further sulfide attack.

Hydrogen sulfide corrosion in Boise is system-wide. Boise officials feel their corrosion problem can be correlated to low flows in hydraulically oversized sewers and to turbulent flows created by force main discharges and drops in manholes. There is very little industry in the area, and Boise operates a completely separate sewer system.

Boise, in consultation with CSDLAC, has tried Polymorphic resin and Zebron coatings and Chrystallok and fiberglass liners in several of their manholes. Insituform and sliplining have been and are presently being used in Boise to rehabilitate corroded sewers.

After Boise discovered its problem in 1983, it realized that the 1977 television monitoring tapes indicated previously overlooked signs of corrosion such as concrete swelling and spalling. During the visit, Boise displayed over 15 samples of 4-inch-diameter cores, recovered from a 1984 coring program, which showed the extent of corrosion in different pipe sizes, ages, and areas of the system.

Based on measurements of core thickness and the known age of the pipe, Boise has calculated that lifetime corrosion rates are as high as 0.12 inches per year in the sewer pipe at Glenwood and Chinden streets, and 0.15 inches per year in the sewer pipe at Canal and

Columbus streets. Corrosion rates calculated similarly for pipe in the warm springs area was 0.03 inches per year over a 37-year period, and 0.06 inches per year at Protest and Federal streets.

About 30 homes in the Warm Springs area use a geothermal water source for home heating. The water is extracted from the ground at about 175°F and discharged from homes to the sewer at about 130°F. The sewage in this area of town averages between 90 and 100°F. The sulfate concentration of this water source is about 23 mg/l. Corroded manholes were observed in this area.

The maintenance supervisor from the neighboring West Boise Sewer District (West Boise) described a serious problem in his system. West Boise replaced six manholes after a 5-year-old sewer collapsed due to hydrogen sulfide corrosion in 1983. There were 10-foot-drop laterals at some of these spun concrete, Type 2 concrete manholes. West Boise feels that hydrogen sulfide conditions are worse at turbulent flow areas (e.g., drop manholes). In addition, the supervisor cited uneven slope during installation of the system as contributing towards solids deposition in the lines.

West Boise previously used chlorine and hydrogen peroxide dosing and experimented unsuccessfully with bacterial seeding to control sulfide generation. The chemical treatment program was successful once the proper dosing was defined, but very expensive. The West Boise maintenance supervisor also feels that hydrogen sulfide conditions are worse at turbulent flow areas resulting from drop manholes. He noted that Garden City, a nearby area with high infiltration and inflow, has little corrosion.

The West Boise Sewage Treatment Plant, owned and operated by Boise City, has had air scrubbing equipment installed to reduce odor emissions.

A tour of Boise's treatment plant revealed some concrete corrosion. Influent channels covered for three years at the plant's headworks have experienced corrosion, particularly the channel that formerly carried sludge. The covered wet wells had no corrosion, but the air has been scrubbed since the 1970s to reduce odor complaints. The remainder of the process tanks at the plant are not covered (except for the anaerobic digesters), and are not experiencing any concrete corrosion.

The field team members made observations at 12 sites in Boise. Of these, five sites (i.e., one at Protest Avenue and Federal Way, and four along a segment of another sewer between North Gary Street at West Baron Street and Glenwood Street at Chinden Boulevard) showed a high rate of corrosion. The remaining sites, although they often have acidic pH levels on walls, do not yet show evidence of corrosion.

The Protest Avenue site is located only 2 miles from the upstream end of the collection area and has a 10-foot-drop inlet. The long drop creates turbulence that is believed to accelerate release of hydrogen sulfide and corrosion. A screwdriver could be pushed up to 2 inches into the remaining concrete of the manhole wall. Measurements of pH were 2 on the manhole wall. This site is 14 years old.

Four sites along a single 12-year-old line between North Gary Street at West Baron Street and Glenwood Street at Chinden Boulevard also have high-rate corrosion. Pipe at the downstream end (Glenwood Street at Chinden Boulevard) showed deep corrugations at reinforcing steel, indicating that corrosion had penetrated deeper than the reinforcement. Surface pH levels were 6 in the pipe and 1 in the manhole at North Gray Street, 3 in the pipe and 1 in the manhole at Bluebird, and 3 in the manhole at State Street. The wastewater sulfide concentration was 2.25 mg/l near the upstream end.

A brick manhole and a previously corroded concrete manhole coated with Polymorphic resin were inspected in the Warm Springs area of Boise. The surface of the brick manhole had a pH of 5, and the coated concrete manhole had a pH of 2.0 - 3.0. Both the brick manhole and the resin coating appeared to be in good condition.

Additional observations at one unlined and two lined manholes did not reveal corrosion. Shallow corrosion, zero to 0.50 inches deep, was observed at a pump station wet well.

A.1.4 Casper, Wyoming

Casper officials feel that a severe hydrogen sulfide corrosion problem exists in that city. The problem first came to light in 1975 during reconstruction of the wastewater treatment facility when a severely corroded influent line to the primary clarifier needed replacement. Since that time, the city has begun looking for corrosion in manholes as part of its manhole inspection program. In addition, the city tried sodium hydroxide dosing once in 1986 and once in 1987 to control the slime layer inside sewer pipes and has added clean water to upstream portions of the system to increase flow rates and decrease detention times. The sodium hydroxide treatments were effective for approximately three-week periods. Generation of hydrogen sulfide is only a problem during summer months. Casper also has a problem with hydrogen sulfide corrosion of the engines being fueled with digester gas in its cogeneration plant. A $16,000 rebuild was recently completed. City staff reported that this digester gas cogeneration problem is shared with Billings, Montana, and Boulder, Colorado.

Casper officials identified seven manholes for the visit. The first observation was in a manhole on a 29-year-old 36-inch sewer line about 0.75 miles from the wastewater treatment facility. The remaining observations were along a 10-mile segment of a 6- to 7-year-old sewer that transports wastewater from the western side of Casper to the wastewater treatment facility.

Corrosion is clearly evident in the 29-year-old manhole. Aggregate is exposed and loose in some instances. Up to 1.5 inches of pipe wall may have washed away. Corrosion product was not observed at this location; however, a pH of 3 was measured on the manhole wall and a pH of 4 to 5 was measured in the crown of the downstream pipe. Corrosion is evident at all the manholes observed on the 6- to 7-year-old sewer.

Furthermore, corrosive conditions appear to worsen the farther downstream that observations were made. The farthest upstream observation was at a manhole located about 200 feet below a force main river crossing. The sewer pipe appeared in very good condition, except for 0.125 inch of erosion evident along the side of the outlet. Pipe and manhole surface pH was 6 at this location; there was no corrosion product.

As the observers progressed to downstream locations, the presence of corrosion product increased and pH levels on pipe and manhole surfaces decreased. Measurements at three downstream locations showed pH levels of 2 or less. At the farthest downstream location, Center and G St., approximately 1.5 inches of soft, mushy corrosion product was evident on the walls of the manhole. Because of the short length of time that this sewer segment had been installed, it was difficult to estimate the amount of concrete that had corroded. However, corrosion was clearly occurring.

The effluent channel of the primary clarifiers at the wastewater treatment facility at Casper had severe corrosion. Up to 2 inches of concrete may be missing from parts of the channel. The facility superintendent believes that a major contributing factor to sulfide generation in that city is excessive sewage detention time. This results from hydraulically oversized sewers constructed in anticipation of growth that did not occur because of a regional economic downturn. In addition, high sulfate concentrations in the local drinking water, 180 to 200 mg/l, may aggravate the problem.

A.1.5 Fort Worth, Texas

The City of Fort Worth maintains approximately 2,000 miles of sewer which transport wastewater to a single treatment facility located adjacent to Village Creek, a tributary of the Trinity River. A second facility, the Riverside facility, used to treat wastewater for the city; however, flow to that facility was diverted to the Village Creek facility several years ago.

Fort Worth experiences hydrogen sulfide odor problems during warm weather and has had a pipe collapse that is attributed to hydrogen sulfide corrosion. In particular, one of the Village Creek collectors collapsed. The city now injects chlorine into the two main interceptors (90 and 96 inches) to control sulfide and odor. The closing of the Riverside Treatment Facility and concomitant shifting of flow to Village Creek have decreased detention time and hydrogen sulfide levels in these two interceptors.

The industrial contribution of wastewater is a fairly uniform 10 to 20 percent throughout the collection system. The major sources are from electroplating, brewing, food processing, and aircraft manufacturing.

The levels of metals in the wastewater have declined dramatically during the past five years. However, levels of aluminum and iron are high because of the discharge of drinking water treatment sludge to the wastewater collection system at several locations.

A pipe collapse was reported to have occurred at the end of a force main in the neighboring City of Grand Prairie. The City of Pantego, also a neighbor, was said to have a major problem.

Field team members entered five manholes in Fort Worth to assess the presence and effects of corrosion in the city sewer system. The manholes are spread out across the city and represent several sewer main subsystems. Two manholes manifested severe corrosion. At Rosedale Street, a section from the crown of a 36-inch pipe is clearly visible lying on the pipe floor. The pipe walls have corrugations 1.5 to 2 inches deep; an estimated 2 to 3 inches of pipe is missing. The city is aware of problems in this 30-plus-year-old line and has rerouted wastewater to allow replacement of this sewer. This sewer has a steep, easily observable slope that increases sewage velocity and could accelerate the release of hydrogen sulfide gas. The pH of the pipe surface at this manhole was approximately 6, indicating that conditions were not as corrosive at the time of the visit as in the past, probably because of the rerouting of the wastewater.

The second location with severe corrosion was a 65-year-old, 54-inch pipe on Bomar Street. At this location, the pipe upstream and downstream of the manhole had corrugations 1 to 2 inches deep. In addition, a section of pipe wall approximately 1 foot high by 6 feet long is missing from the right side of the pipe approximately 15 feet downstream. An estimated 2 inches of concrete has eroded from the lower portion of the manhole, and the joint between the manhole and outlet pipe has deteriorated. Two 15-inch laterals enter this manhole, but do not appear to be very active. The upstream manhole has an active drop lateral, and flow in the downstream manhole is very turbulent. In both instances, these factors could have contributed to release of hydrogen sulfide gas and an increased corrosion rate. The pH of the pipe surface at this manhole was approximately 6. There is no apparent indication of current or ongoing corrosion.

The other three manholes observed in Fort Worth are approximately 30 years old. Even though these locations had lower pH levels of 4 to 5, corrosion is not as severe as at the other two locations. Drop laterals were not observed at or near these three locations.

A.1.6 Seattle, Washington

The Municipality of Metropolitan Seattle (Metro) maintains approximately 247 miles of sewer which transport 186 mgd of wastewater to Metro's treatment facilities. Metro has had a hydrogen sulfide odor problem for many years. A large number of its concrete sewers and sewage structures have experienced extensive corrosion damage. The most serious identified cases of hydrogen sulfide corrosion have been replaced or repaired by coatings or liners.

Construction of Metro's interceptor facilities began in 1963; corrosion is widespread in this relatively new system. Local municipalities provide smaller-diameter sewage collection systems which were not investigated during this study. The Seattle area is heavily industrialized, and industrial flow represents about 25 percent of the total flow; however, industrial discharges have not been correlated with sulfide generation or concrete corrosion.

Areas served by Metro to the east and north of Lake Washington have separate sewer systems for stormwater transport. Areas to the west of Lake Washington are served predominantly by a combined sanitary-stormwater sewer system.

Metro has an extensive sulfide monitoring program, and has had full-time staff working on the problem since early 1987. Metro personnel look for hydrogen sulfide damage as part of sewer inspections during which headspace hydrogen sulfide concentrations and pipe surface pH levels are also measured. Hydrogen sulfide concentrations from 0.1 to over 50 ppm have been found along with pH readings as low as 2. Metro's records indicate lower pH readings occur at sites with higher hydrogen sulfide gas concentrations.

Metro has tried various concrete liners and coatings in pipes and on structures to control corrosion as well as chemical addition to control sulfide. Sliplining, epoxy, polyethylene (PE), PVC, UPC (a polyurethane polyethylene copolymer), Ameron lining, polyurethane (Sancon), C.T.E. coating, and Aquatapoxy all are being or have been tested by Metro since 1974. Both satisfactory and unsatisfactory performances have been observed. For example, the PE liner on the East Bay Interceptor - Section 8 is in good shape and is protecting the concrete behind it, but the UPC coating on the Lake Sammanish Interceptor failed and is peeling off. Hydrogen peroxide addition to control sulfide was tried but abandoned for monetary reasons. However, Metro did find that once a large shock dose of peroxide was added, subsequent dosages could be reduced to control sulfide.

Metro has been involved in other activities related to hydrogen sulfide corrosion control. Power cleaning of sewers, use of sacrificial concrete in its sewers, and sonar, radar and ultrasonic measurement of pipe wall thickness have been tried. Metro has also tried to monitor corrosion rate with concrete coupons and copper shavings hanging in pipes; but found reactions too slow to provide useful data. In addition, the Renton Treatment Plant has a $5,000,000 odor-control system employing scrubbers, activated carbon, impregnated carbon, and chlorine addition. A facilities plan study by a consultant included sulfide-control recommendations. Concrete corrosion at Metro's treatment plants is not a problem.

Seattle Metro personnel recommended five sites for observation. The sites are widely distributed throughout the system and in parts of different subsystems. Three sites are directly downstream of force main discharges: a manhole at East Marginal Way and South 112th Street, downstream of the Renton sludge force main; a manhole near 15th Avenue W and W Raye streets, downstream of the Interbay Pump Station force main; and the Hollywood Pump Station discharge structure. One of the remaining sites, a manhole at 15th Avenue NW and 188th Street NW, is a few blocks downstream from a force main. The fifth site, a manhole on the Lake Sammanish Interceptor at NE Union Hill and Avondale roads, is not downstream of a force main.

Concrete pipe downstream of both the Renton and the Interbay force main discharges has experienced severe corrosion. Corrosion appears to have penetrated the second layer of aggregate (1-inch loss) leaving only a short distance to reinforcing steel in the pipe downstream of the Renton force main. The surface pH averaged 1.8. The sewer downstream of the Interbay force main carries combined flow and occasionally surcharges. The 21-year-old sewer pipe was PVC-lined in 1978 for about 200 feet downstream of the Interbay force main; however, severe corrosion begins where the liner ends. Assuming that the corrosion all occurred in the seven years following the lining, the corrosion rate at the Interbay site is over 0.2 inches per year. Rust spots are visible on the unlined concrete pipe wall, indicating that reinforcing steel will likely be exposed soon. One and one-half inch is estimated to be missing. Measurements of surface pH average 1.3 at Interbay.

Exposed aggregate and corrosion were observed around the flap gates at the Hollywood Pump Station discharge and on concrete not protected by a PVC lining. However, most of this structure is PVC-lined. The exposed portions are probably exposed to erosional forces when the pumps discharge.

The manhole at Union Hill and Avondale roads showed shallow corrosion, zero to 0.50

inches deep, and had a surface pH of 3. The inlet and outlet pipes to this manhole were in good condition, even though the UPC lining was in poor condition. The site at 15th Avenue and 188th Street NW also showed only shallow corrosion, which was limited to the outlet pipe. This sewer carries combined sanitary-stormwater flows. The surface pH level averaged 1.2 at this site. A wastewater total sulfide concentration of 0.6 mg/l was measured at the Union Hill Road site.

The frequent presence of force mains, required to overcome topographic barriers, appears to increase the hydrogen sulfide corrosion problem in Seattle. Seattle feels industrial metal bearing discharges have no correlation with corrosion, since that industry has always had pretreatment standards.

A.1.7 Charlotte, North Carolina

In the Charlotte-Mecklenburg Utility District (CMUD) system, EPA compared corrosion conditions in purely domestic sewers with conditions in sewers that carry industrial flow. Approximately 15 metal finishers and a large foundry are permitted for discharge into the CMUD sewer system. The field team entered six sewers with a large flow contribution from industry and four sewers with only domestic flow.

CMUD personnel were not aware of system-wide hydrogen sulfide corrosion problems, although a failure occurred in the Briar Creek sewer sometime prior to 1973. Since that time, CMUD has been specifying tricalcium phosphorus as an additive to its concrete pipe. CMUD also currently specifies a 1-inch sacrificial layer of concrete in its pipe. In the late 1960s, CMUD had an odor study done on the Briar Creek Sewer; it implemented a program of hydrogen peroxide addition for odor control in 1974. The hydrogen peroxide was added to a point about 3 miles upstream of the Sugar Creek Treatment Plant to which the Briar Creek sewer is tributary. This action was unrelated to the prior Briar Creek failure. Strong odors at the Sugar Creek treatment facility prompted another odor study in the late 1970s. The second study lead to the injection of hydrogen peroxide at a location

0.50 miles upstream in both 54-inch influent lines to the plant.

The Charlotte water supply is categorized as "soft" by CMUD and has a 8.0- to 9.0-ppm total sulfate concentration.

Two of the domestic sites (Davidson Street at East 22nd Street, and Myers Street at East 12th Street) are in the Sugar Creek drainage area and two (Arborway near Sedley Road, and Old Providence Road near Sharonview Road) are in the McAlpine Creek drainage area. The Sugar Creek sites are 7 and 6 miles from the treatment plant, and 5 and 6 miles from the upstream end of the same drainage area, respectively. The McAlpine Creek sites are 7 and 8 miles from the treatment plant, and 3 and 10 miles from the upstream end of their respective drainage areas. All pipe observed in the CMUD system is 20 to 25 years old. Wastewater sulfide concentrations at the four sites ranged from 0.2 to 0.6 mg/l. Wastewater pH measurements were 6 at three sites, and 5.5 at the Old Providence Road site. It was the only site in Charlotte with pipe and manhole surface pH measurements below 6. Pipe surface pH measurements were 4.5 to 5. Corrosion product extended about 0.25 inches deep, exposing "peastone" aggregate at this site.

Two of the four domestic sites experience turbulent flows due to a bend and an obstruction. Although the wastewater contained measurable concentrations of sulfide at each site (0.6 mg/l and 0.4 mg/l), there was no measurable headspace hydrogen sulfide. The Old Providence Road site has a 42-inch pipe and was flowing half full at about 2 fps when observed. The three clean pipes ranged in size from 24 to 54 inches in diameter.

Three of the industrial sewers (Clanton Road at the Irwin Creek Bridge, Remount Road at the municipal park, and Freedom Drive at Thrift Road) are in the Irwin Creek drainage area, 1 to 6 miles from the treatment plant, and 5 to 10 miles from the upstream end of the same drainage area. Two of the industrial sewers (Old Nations Ford Road near Ervin Lane, and Granite Street near Continental Boulevard) are located in the McAlpine Creek drainage area. The remaining industrial site is located next to Park Road near Moncure

Drive in the Sugar Creek drainage area. The McAlpine Creek sites are located approximately 10 and 7 miles, respectively, from the farthest upstream points in their drainage areas. The Granite Street site is about 1 mile downstream of a 12,000-foot, 24-inch-diameter force main; the wastewater pH was 5.5 at this site. The Park Road site is located about 7 miles from the farthest upstream point in its drainage area.

Two of the six industrial sites showed signs of very shallow hydrogen sulfide corrosion. The Remount Road site had lost just enough concrete to expose aggregate and also had turbulent flow. The Granite site had turbulent flow and an observed velocity of approximately 10 fps. This site also had four consecutive drop manholes upstream. Pipe wall and manhole surface pH measurements were pH 6, and some corrosion product was observed. Wastewater pH measurements were 6 at four of the industrial sites, 5.5 at one site, and 10 at the remaining site. Wastewater sulfide ranged from 0.0 to 0.3 mg/l. The wastewater sulfide level was 0.05 mg/l at the site where wastewater pH was 5.5, and 0.0 mg/l at the site where wastewater pH was 10. There was no measurable headspace hydrogen sulfide gas at any of the six industrial sites.

Pipe diameter at the industrial sites ranges from 21 to 54 inches, and all pipes are approximately 20 years old. The observed flows range from one-third to two-thirds full, from smooth to extremely turbulent, with velocities typically 2 to 4 fps.

A.1.8 Milwaukee, Wisconsin

The Milwaukee Metropolitan Sewerage District (MMSD) maintains approximately 305 miles of sewer and two treatment facilities which serve approximately one million people in the Milwaukee area. The average daily wastewater flow is 190 mgd, of which industrial flows represent over 25 percent. MMSD estimates that 15 percent of the area served by its system contributes storm flow. Wet weather flows at both treatment plants double dry weather flows. The average biochemical oxygen demand (BOD) is 200 mg/l, and total suspended solids (TSS) is 250 mg/l at the two plants.

In the MMSD system, EPA compared corrosion conditions in purely domestic sewers to conditions in sewers that carry industrial flow. Approximately 90 electroplaters and metal finishers and about 15 tanneries are permitted for discharge into the MMSD sewer under its pretreatment program. Some of the permitted tanneries have waivers to discharge wastewater without pretreatment for sulfide, making data obtained from the MMSD system particularly pertinent to this study. Observations covered five sewers with only residential flow and five sewers with a heavy industrial contribution to the flow.

MMSD personnel were not aware of any hydrogen sulfide corrosion problems. The District recently inspected (by television) 20 percent of its large-diameter pipe. Annually, it inspects an additional 40,000 feet. MMSD also manually inspects manholes and sewers during a standard manhole step replacement program and a seasonal manhole cleaning program. MMSD has some odor problems; however, these are located in parts of the system where the odors do not generate public complaints.

Three of the residential sites are in the northern part of the service area, 4 to 6 miles from the Jones Island Treatment Plant, and 3 to 5 miles from the upstream end of the system. Pipe ages at these sites range from 50 to 70 years old. None of the three sites revealed any wastewater sulfide. Wastewater pHs were all 6.5, and pipe and manhole surface pHs were all 6.5. (According to carbonate chemistry, one would expect weathered concrete to be about pH 6.3.) No corrosion or signs of corrosion of pipe or manhole concrete were observed at these sites, even though one site is a junction structure and another site is located just downstream of a pump station. In both cases, these locations often experience turbulent flow and potential release of hydrogen sulfide gas.

The other two residential sites, located in the South Shore Treatment Plant basins, are 8 to 10 miles from the treatment plant, and 3 to 5 miles from the upstream end of the basin. The first site is less than 20 years old, and the second site, Kinnickinnic, is 50 years old. Observations at the 20-year-old site were similar to those at the first three residential sites. However, a wastewater sulfide content of 0.5 mg/l was found at the Kinnickinnic site and pH of 3.5 was measured on the crown of the downstream pipe. Kinnickinnic had severe corrosion from the water line up the pipe about 1 foot. Up to 1 inch of concrete appeared lost as estimated by aggregate exposure in this 36-inch-diameter pipe. A black slime growth was observed from 1 inch above the normal water line to 2 inches below.

Five sites had large amounts of industrial flow. Three sites are about 2 to 3 miles north of the Jones Island Treatment Plant and two are immediately upstream of the plant. All five sites are at least six miles from the upstream end of the system and are at least 40 years old. Corrosion was not observed at any of these sites.

Two of the industrial sites had measurable sulfide in the wastewater: 0.18 and 0.40 mg/l. Wastewater pH ranged between 6.5 and 7.5. Pipe and manhole surface pH measurements ranged between 6.0 and 7.0. One of the industrial sites was located less than 0.5 miles downstream from a tannery. Two sites had initial hydrogen sulfide gas concentrations of between 0.5 and 0.6 ppm in the pipe headspace. One site located in the downtown industrial area could not be entered because of a photoionization meter reading of greater than 1,000 ppm. Two sites had abrupt changes in direction 20 to 30 feet upstream from the manhole and 6 to 8 inches of bottom debris. Typical at these sites was a grease buildup on pipe and manhole walls, calcium buildup, and slime, but solid concrete pipe underneath.

A.2 Wastewater Treatment Plants and Pump Stations

Site investigations were conducted at five wastewater treatment plants in three cities. The purpose of these investigations was to document the location, nature and severity of hydrogen sulfide corrosion problems at these facilities. The wastewater treatment plants included the Hookers Point facility in Tampa, FL, the East Bank and West Bank plants in New Orleans, LA, and the Hyperion and Terminal Island plants in Los Angeles, CA. Pump station corrosion was also investigated as part of these site visits.

The type and extent of information available from the various cities varied widely. Some cities closely monitored hydrogen sulfide levels in the wastewater and in the atmosphere, and maintained detailed records of corrosion repair and rehabilitation efforts. Others had done little to monitor or control corrosion.

The following provides a summary of the information collected from the site visits to cities where corrosion was believed to be a problem in the wastewater treatment plant and pump stations.

A.2.1 Tampa, Florida

The Hooker's Point Advanced Wastewater Treatment Plant was expanded in 1978 to handle a design flow of 60 mgd. The plant is averaging approximately 57 mgd, and employs advanced waste treatment (AWT) for biological nitrogen removal. Unit processes at the plant include influent screens and grit chambers, primary clarification, two stage activated sludge treatment, secondary clarification, denitrifying filtration, chlorination and dechlorination. The plant achieves nitrification/denitrification before it discharges to Tampa Bay. Sludge handling processes are varied, and consist of gravity, dissolved air flotation, or belt filter thickening of waste activated sludge, anaerobic or aerobic digestion, and belt press or drying bed dewatering. A new sludge dryer and pelletizer will come on-line in the fall of 1990.

Hydrogen sulfide corrosion at the wastewater treatment plant is very severe. The walls of the influent junction box were constructed with a corrosion-resistant plastic liner. H_2S corrosion is also severe in the screen and grit building and in the effluent chamber in the grit building. Dissolved sulfide is approximately 10 mg/l in the influent wastewater. Concrete on the roof of the junction box had also corroded to an extent that the aggregate was exposed. All mechanical equipment showed mild to severe corrosion. Hand rails, platform, and other structures at the primary clarifiers were corroded.

The plant expends significant resources to combat hydrogen sulfide corrosion. All carbon steel parts have been replaced by stainless steel parts wherever possible. Electrical components have been covered and electrical sockets replaced using plastic materials. A very rigorous painting schedule is maintained on all equipment and parts at the junction chamber. H_2S levels in the atmosphere of the screen and grit building are as high as 20 ppm. A fine-mist scrubber was installed to treat the H_2S-laden air emissions from the junction box. Although designed to handle 50 ppm of H_2S, levels entering the scrubber range from 400 to over 1000 ppm. The capital cost of the scrubber system was approximately $1,000,000. Annual operating cost is estimated to be $400,000/yr.

The primary clarifiers at the wastewater treatment plant are also at an advanced stage of corrosion. Some clarifiers are 40 years old and the others were built during the expansion. There is little corrosion at the influent end of the clarifiers but severe corrosion at the effluent end. The wastewater has a fall of four feet in the effluent channel thereby creating turbulence and releasing H_2S to the atmosphere with the result that the concrete structure at the effluent channel is severely corroded.

Most of the moving parts on the clarifiers have been replaced by plastic, including the scraper mechanism. Gear motors and electrical/mechanical components are covered with corrosive-resistant materials. Approximately 2 to 4 inches of the side walls at the effluent channel in the primary clarifiers have been lost due to corrosion. At some locations, reinforcing steel was visible. The rehabilitation of the clarifiers is now under contract and includes the installation of a plastic liner on the walls. Hydrogen sulfide corrosion downstream of the clarifiers is very limited. There is very little hydrogen sulfide corrosion found at other treatment processes and sludge handling facilities.

Hydrogen sulfide corrosion of instrumentation and controls at the wastewater treatment plant was severe at the transformer cabinets. All copper tubing and wiring corrodes rapidly. Corrosion of electrical contacts was widely observed. Switchgear at the influent junction chamber also corrodes rapidly. Corrosion prevention measures for instrumentation and control equipment includes covering the instruments, purging with clean air, and air conditioning control rooms. All electrical equipment at the plant is on a preventative maintenance and painting schedule. Contacts and relays are cleaned regularly. Transformer housings must be replaced periodically.

Although corrosion of sludge handling components and structures has been a problem in the past, such problems have largely been eliminated through gradual replacement with corrosion resistant materials such as galvanized and stainless steel. Spare parts are stored in an air-conditioned warehouse to prevent corrosion. Minor corrosion problems are still evident where components such as conduit fittings are not available in corrosion resistant materials.

There are 160 lift stations in the sewer system that collect and transport wastewater to the treatment plant. The more recent pump lift stations are built of concrete.

Medium to very high rate corrosion was found at many of the lift stations. Most of the manholes, wet wells and interior control room walls in lift stations have sulfur (yellow) deposits. There was severe corrosion near turbulent areas of the lift stations. The concrete was corroded and reinforcing steel was visible. Most of the lift stations have mild to severe corrosion present. Steel sound enclosures over wet wells had to be replaced by fiberglass buildings. Most of the larger pump stations have fine-mist scrubber systems. The City tried a hydrogen peroxide dosing system, but it was judged to be too expensive to operate. A few lift stations have used a ferrous sulfate dosing system to control H_2S. The City also tried packed tower air scrubbers. They were very high in maintenance. Carbon adsorption systems were also installed on some lift stations.

Corrosion of instrumentation and control systems at the lift stations was not quite as severe as at the plant. This was primarily due to the active preventative maintenance program imposed by the City. Copper tubing and exposed wiring were seen to be corroded. All motor control centers and electrical equipment were covered.

A.2.2 New Orleans

The East Bank and West Bank wastewater treatment plants of the City of New Orleans were visited to document the extent of hydrogen sulfide corrosion at the facilities. The East Bank plant treats the sanitary flows from downtown and the northeast part of the City. The plant was originally built in 1963 for primary treatment and was later expanded for secondary treatment in 1980. The original design flow at the plant was 30 mgd but the facility has been expanded to handle 122 mgd. A total of 1500 miles of collection system comprised of gravity and force mains collect and convey sewage to the plant. The treatment plant consist of screens and grit removal, pure oxygen activated sludge system and secondary settling. Effluent is discharged to the Mississippi River. Secondary sludge is dewatered and then incinerated. The ash, along with screenings and grit, are disposed of in a sanitary landfill.

Plant headworks at the East Bank plant had severe corrosion in the screen and grit basins. Some parts of the grit basins were built in 1963 and were then expanded to meet the new design flows. Three force mains feed wastewater to these grit basins. One force main conveying flows from the City has long detention times, and hence the wastewater is very septic when it reaches the plant. The color of the wastewater was very dark (black) and was deficient in D.O.

The side walls of the grit chamber were severely corroded. Approximately 1 to 1½ inches of concrete was corroded away at some locations. Severe corrosion was also observed at the effluent end of the grit box where the wastewater spills into a channel which led it to the pure oxygen activated sludge tanks. The grit chambers were installed with screens on each pass. These screens were in a deteriorated condition. Many of the components of the screens had rusted and the metal frames on which they were attached were corroded along with the concrete below the frames.

Corrosion of instrumentation and controls was found to be severe at the East Bank plant.

Contacts on electrical equipment were oxidized. The plant personnel replace small items and clean contacts and equipment on an annual basis. They sometimes must take equipment off-line for service and maintenance. As preventative maintenance, they use a light coating of oil, and cabinets purged with cleaned air. The plant has entered into an annual preventative maintenance contract. They allocate two men 1 to 1-1/2 days/wk for electrical equipment maintenance. The electrical contacts on indicator lights, pump relays, and contacts operate intermittently because of oxidation problems at the contacts. The instrument control room is fully air conditioned. Air cleaning is done through permanganate beads which are replaced every month. The plant expends significant effort for replacement and maintenance of the electrical and instrumentation components.

The plant does not have any control measures to prevent future corrosion. No efforts have been made to rehabilitate the corroded structures. The plant has a limited budget and does not plan to employ rehabilitation of structures as a corrective action until there is a failure.

The West Bank plant serves the population of the western side of the City of New Orleans. The plant was originally built in 1971 for a design maximum flow of 15 mgd. The average dry weather flow (ADF) to the plant is approximately 7 to 8 mgd. The plant is now under design for expansion to 40 mgd. The treatment plant consists of influent bar screens, grit removal, primary sedimentation, high rate trickling filters, secondary sedimentation, chlorine contact and final discharge to the river. The sludge from the clarifiers goes to a thickener and a vacuum filter and is then incinerated. The ash from the incinerator is disposed of in a local landfill.

The West Bank plant also has severe corrosion at the influent head box where the screens and grit chamber are located. Corrosion has degraded the sidewalls on the grit chamber to a depth of 1 to 1½ inches. Again, corrosion was found to be severe at areas of high turbulence i.e. at the influent and effluent end of the grit basins. The metal grating and handrails on the grit basins were also corroded. The wastewater entering the plant was septic and the dissolved oxygen was always found to be 0 mg/l except during heavy rainfalls when the D.O. would increase to 0.2 mg/l. As the plant is located adjacent to a golf course, there are plans to cover the plant headworks, the sludge thickener and some other tanks to control odor emissions.

There are no efforts being taken to rehabilitate the degraded structures. No rehabilitative techniques have been employed to correct the odor and corrosion problems.

The vacuum filters at the West Bank Plant are located in a building that is equipped with a passive air ventilation system. The mechanical and support parts of the vacuum filters are in a severely corroded state. The plant had to replace grating over the filter supports. When the filters are operating, high H_2S levels are reported in the building. There is no corrosion reported at other parts of the plant. Corrosion at instrumentation and controls is minimal. Corrective action at this plant is based primarily on minimizing odors which are affecting the neighboring golf course.

There are a total of 87 lift stations and 1500 miles of sewers that serve both the East and West Bank Treatment Plants in the City of New Orleans. The lift station wet wells are made of brick and concrete. Force mains range in size from 42 to 52 inches and are constructed of cast iron, steel or concrete. Ninety to 95 percent of the collection system is 8 to 10 inch diameter pipes. Concrete pipes were laid in late 1930's. There are a few older pipes made of clay. Since the 1970's, plastic pipe has been used where possible.

All of the 87 lift stations employed in the collection systems for the East Bank and West Bank plants are in some stage of corrosion. The older lift station wet wells were built of brick and are severely deteriorated. The pump base and supports have corroded and at some places are on the verge of falling down into the wet well. Rehabilitation of brick wet wells consists of coating by gunite. The New Orleans Sewage Board experimented with pump cycle times to minimize detention times and decrease H_2S levels. Continuous ventilation is provided in the lift stations at six air changes per hour. At some places the

Board has tried adding ferric chloride but found that it forms clinkers in the incinerator at the plant. H_2S levels in the atmosphere of the wet wells average approximately 100 ppm. The Board spends around $5.2 million per year for lift station maintenance. About 30 percent of total man hours is utilized for lift station maintenance. Electrical and instrumentation equipment have minor corrosion problems. New electrical equipment has been installed with clean air supplied by treatment through potassium permanganate. There is reported to be more corrosion in lift station wet wells at the east side of town.

A.2.3 City of Los Angeles

A.2.3.1 Hyperion Wastewater Treatment Plant

The plant is designed for 400 mgd through primary treatment and 150 mgd through secondary treatment. Present day flows are 370 mgd and 200 mgd, respectively. The ability of the secondary process to handle the additional flow is attributed to the addition of fine bubble diffusers. The headworks, primaries, secondaries and anaerobic digesters are approximately 40 years old. Regulations eliminating ocean sludge disposal and requiring full secondary treatment, along with population growth, have resulted in 10 years of construction at the plant. The City foresees at least another 5 to 10 years at the same pace. The latter includes replacement of the existing secondary process with a pure oxygen process.

With the exception of the gravity degritter in the east headworks, all trash and grit removal tankage are under cover, making direct observation of corrosion on these processes difficult without considerable expenditure of staff manpower. The covers on the west aerated grit chamber effluent channel were small enough to be managed by one person and were lifted for observation. Corrosion of the concrete sewer at those points was observed to be severe, with penetration to at least 12 inches at the water line diminishing to 1 to 2 inches in the closed channel and 0 to 1 inch at ground level of the open tank. The plant carpentry superintendent in charge of all in-house concrete repair indicated the observed areas were typical of all headworks tankage of the same age. The cost of these repairs are not segregated from general plant maintenance costs.

The extent of corrosion below the water line in both tanks and channels was described as minor (less than 1 inch) even in the oldest tankage. All covers (tank and channel) and deck plates are made of aluminum, as were handrails, conduit and other hardware (some stainless steel). No corrosion of these materials was apparent.

The headworks processes are all contained in buildings. The ambient atmosphere of the buildings is swept by fans and discharged to a collection point at the suction of the secondary process blowers. Thus a slight negative pressure is maintained in each building. This prevents noxious odors from escaping the plant and with normal infiltration plus some outside air intakes, avoids the build up of corrosive gases in the atmosphere of the process buildings. All windows in the aerated grit chamber building were sealed in order to reduce escape of hydrogen sulfide, even though the tanks are covered. The few pieces of carbon and galvanized steel found in the buildings were severely corroded. This was especially true of steel doors. No maintenance program is in force for the doors other than repainting when scratched or chipped. The ambient air removal system piping is fiberglass and most other piping is PVC. Conduit is aluminum or PVC.

A short section of the force main entering the plant collapsed and was replaced in 1987. The collapse was attributed to corrosion-weakened concrete pipe combined with the ground vibration caused by heavy construction equipment.

The decision to rehabilitate or replace all or part of the headworks has yet to be made. There is obvious structural damage in some places and some doubt in the mind of staff as to the structural integrity of a rehabilitation effort given the frequency of earthquakes in the area. In either case, PVC liners with concrete slabs will be used in all channels and the inside of all tankage will be at least coated with coal tar or an alternative coating material.

The primary clarifiers are covered with concrete slabs so casual inspection was not possible. The influent and effluent channels are covered by aluminum plates which can be easily removed for inspection. Like the headworks, concrete exhibited deep corrosion penetration from the water line to the surface, with some of the deepest penetration (6 to 8 inches) at the surface adjacent to the channel covers. Most of the corrosion at the top has been repaired by cutting back to good concrete, reforming to the original geometry and grouting. These repairs are recent, and are not covered by any protective coating. An epoxy-type coating had been applied to the early patches and began peeling almost immediately, so coating was discontinued. The channels will be covered with PVC liners. The type of coating for the inside of tank walls and covers is as yet undetermined. They are in the process of converting from steel to plastic chain and from wood to fiber glass boards for the sludge rakes. The existing primaries will be rehabilitated once new primary construction is complete.

With the exception of anaerobic digestion, the sludge handling processes came on-line in 1985-1986. Ocean disposal of sludge ceased in 1987, and digested sludge is now either dried and applied to power generation (Carver-Greenfield process) or dewatered by centrifuges and transported to a Yuma, AZ land application site. Due to safety regulations for construction at the site, the sludge handling facility was off-limits to visitors. The addition of ferrous chloride (280 mg/l) for hydrogen sulfide reduction after sludge digestion is to control sulfur emissions as opposed to corrosion control.

All instrumentation and control electronic equipment is conformably coated (a thin lacquer-like coating applied to circuit boards and components to seal them from the atmosphere) in the manufacturing process. This is standard practice in the industry for wastewater treatment equipment suppliers. In addition, all field mounted instrumentation (sensors, transmitters, etc.) are nitrogen purged. The case of each instrument is connected to a low pressure nitrogen supply which maintains a slight positive pressure in the instrument housing to prevent exposure of the components to ambient air. Inspection of the equipment disclosed no sign of corrosion. All circuit boards, contacts, wire terminations and other exposed metal was bright and shiny. The annual cost of nitrogen is estimated at less than $3,000. The only sensing elements immersed in liquid process streams are DO probes. These are newly installed and as yet have no track record. The control room is isolated from ambient atmosphere by scrubbing, filtering, and air conditioning. No problems were reported or apparent with these systems.

Although not as severe, there is ample evidence of concrete corrosion in secondary treatment. The worst is at the aeration basin influent mixing channel where corrosion has penetrated to the reinforcing steel (2 inches). Other areas of the reactors have exposed aggregate. Steel hand rails and steel plate on the side of the reactors are pitted and rusted where chipped or peeled paint allowed exposure to atmosphere.

Since a new oxygen activated sludge system is planned, only those repairs necessary for the existing system to remain operational will be made.

The scavenged air recovered from buildings and below tank covers is ducted to the aeration basin blowers for scrubbing in the activated sludge mixed liquor. This air is not cleaned by other than conventional blower inlet air filters, nor are the blowers constructed of special corrosion resistant materials. This has not caused any additional blower maintenance or reduced the useful life of the blowers. The only impact is on the carbon steel linkage that moves the internal guide vanes and this impact is considered minor by the maintenance staff.

A.2.3.2 Terminal Island Wastewater Treatment Plant

The original plant was constructed in 1935 and completely rehabilitated in 1977. The plant is designed for full secondary treatment of 30 mgd. Present day dry weather diurnal flow ranges were modified from 5 to 35 mgd, a 7:1 ratio, to 10 to 30 mgd, a 3:1 ratio, by requiring (as part of pretreatment enforcement) local industries to shift discharges to off-peak hours. Over 50 percent of the flow and 70 percent of the load is of industrial origin.

With the exception of the bar screen, all trash and grit removal tankage is under cover, making direct observation of corrosion on these processes difficult without considerable expenditure of staff manpower. Corrosion of the concrete at the bar screens was negligible at those points observed, with penetration barely to the aggregate at the water line. The extent of corrosion below the water line in both tanks and channels was described as minor (less than 1 inch) in the oldest tankage. All covers (tank and channel) and deck plates are made of aluminum, as were handrails, conduit and other hardware (some stainless steel). No corrosion of this material was apparent. The bar screen frame and sheet metal is of coated (coal tar) carbon steel, which was severely corroded. Most of the sheet metal has been replaced with sheet PVC. The frame (¼ inch angle iron) will probably be replaced with stainless steel.

The headworks processes are all contained in buildings. The ambient atmosphere of the buildings is collected by the suction of the secondary process blowers (no fans). Thus a slight negative pressure is maintained in each building. This prevents noxious odors from escaping the plant and with normal infiltration plus some outside air intakes, avoids the build up of corrosive gasses in the atmosphere of the process buildings. The few pieces of carbon steel found in the buildings were severely corroded including galvanized steel hardware. This was especially true of steel doors. No maintenance program is in force for the doors other than repainting when scratched or chipped.

The ambient air removal system piping is fiberglass and most other piping is PVC. Conduit is aluminum or PVC.

The primary clarifiers are fitted with aluminum covers. The influent and effluent channels are also covered by aluminum plates which can be easily removed for inspection. Plant staff had previously converted from steel to plastic chain and from wood to fiberglass boards for the sludge rakes. Because of problems with the plastic chain jumping the sprockets, they are converting back to steel chain.

The egg shaped anaerobic digesters appear to be in good condition externally. An external pipe that collects gas for mixing has been replaced with a welded stainless steel pipe. The sacrificial anodes are replaced routinely as part of the maintenance program. The motorized valves located on top of the digesters are also being replaced, but this is because they do not have weather proof housings, although the problem may have been exacerbated by hydrogen sulfide. The earth ground bonding wire (bare copper) in this location has almost turned to dust and is being replaced with an insulated wire. This location is also exposed to winds from the sea, and the corrosion observed may be the result of salt air. The elevator at this location is a high maintenance item, since it is exposed to both sea air and ambient hydrogen sulfide.

The addition of ferrous chloride (450 mg/l) for hydrogen sulfide reduction (10 fold) after sludge digestion is to control sulfur emissions as opposed to corrosion control.

All instrumentation and control electronic equipment is conformably coated. In addition, all field mounted instrumentation (sensors, transmitters, etc.) are nitrogen purged. The case of each instrument is connected to a low pressure in the instrument housing to prevent exposure of the components to ambient air. Inspection of the equipment disclosed no sign of corrosion. All circuit boards, contacts, wire terminations and other exposed metal was bright and shiny. The annual cost of nitrogen is estimated at less than $2,000. The only sensing elements immersed in liquid process streams are DO probes. These are relatively new yet have performed well to date. The control room is isolated from ambient atmosphere by scrubbing, filtering, and air conditioning. No problems were reported or apparent with this system.

The scavenged air recovered from buildings and below tank covers is ducted to the aeration basin blowers for scrubbing in the activated sludge mixed liquor. This air is not cleaned by other than conventional blower inlet air filters, nor are the blowers constructed of special corrosion resistant materials. This has not caused any additional blower maintenance or reduced the useful life of the blowers. The only impact is on the carbon steel linkage that moves the internal vanes and this impact is considered minor by the maintenance staff.

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[ ] other ________________
[ ] local official
[ ] state official
[ ] Federal official
[ ] researcher
[ ] student
[ ] teacher

Name and Phone No. (optional)____

[ ] This document is what I was looking for.
[ ] I would like a workshop/seminar based on this document.
[ ] I had trouble [ ]finding [ ]ordering [ ]receiving this document.
[ ] The document was especially helpful in the following ways:

[ ] The document could be improved as follows:

[ ] I was unable to meet my need with this document. What I really need is:

[ ] I found the following things in this document which I believe are wrong:

[ ] What other types of technical assistance do you need?

We thank you for helping us serve you better. To return this questionnaire, tear it out, fold it, staple it, put a stamp on it and mail it. Otherwise, it may be faxed to 202-260- 0116

EPA MTB
Office of Wastewater Enforcement & Compliance
MUNICIPAL TECHNOLOGY BRANCH

DETECTION, CONTROL, AND CORRECTION OF HYDROGEN SULFIDE CORROSION IN EXISTING WASTEWATER SYSTEMS