

Corrosion Control in Sewers

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Cement concrete sewers, either cast-in-place or pre-cast (like spun pipes or hume pipes), have been used for over a century for large sewers. In the presence of high concentrations of dissolved sulphide, sewers are likely to suffer serious damage when the hydrogen sulphide generated in them is oxidised to sulphuric acid. The first indication of possible trouble to concrete structures from H_2S was given by Hering in 1881¹. The whole process involves two biochemical and one chemical reactions wherein :

- (1) H_2S is formed.
- (2) soluble sulphide is oxidised to sulphuric acid, and
- (3) concrete is attacked by the sulphuric acid.

The processes, which have been critically reviewed² in another paper are briefly described below :

BIOLOGICAL FACTORS OF CORROSION

Generation of Hydrogen Sulphide

Hydrogen sulphide may be produced biologically in sewers by

- (i) hydrolysis of organic compounds containing sulphur, such as, cysteine and cystine, and/or
- (ii) reduction of sulphates

Sewage contains a variety of sulphur-bearing organic compounds, such as, the amino acids, B-vitamins, and inorganics, such as, the sulphates, thiosulphates and thiocyanates. Many bacteria liberate H_2S under anaerobic conditions by a process known as desulphydration such as the one shown below :



Hydrogen sulphide may also be produced by reduction of sulphate by certain anaerobic bacteria, the predominant one being *Desulphovibrio* species. Morphologically these cells are curved rods that move about by means of a single polar flagellum. Physiologically these bacteria are anaerobes which produce H_2S at a rapid rate.³ *Desulphovibrio desulphubicans* appears to be one of the most ubiquitous species in nature. Sulphate is used by the anaerobic bacteria as a hydrogen acceptor for oxidising organic materials, such as, organic acids, alcohols, amino acids and carbohydrates. A likely mechanism of H_2S formation is known to follow a step-wise reduction via sulphate, sulphydrylate, and sulphur hydrate.

Sewage usually contains 1 to 5 mg/l of organic sulphur compounds while some industrial wastes, such as, wool scouring wastes contain 50-100 ppm. Sulphates are invariably present in sewage almost

entirely as inorganic sulphates entering through the drinking water, industrial water or sea water intrusion.

Pomeroy and Bowlus⁴ after an extensive study on this subject found that most of the H₂S generation occurred in the slime layer that developed on the underwater surface of the pipe. Baumgratner⁵ stated that H₂S production was increased by the deposition of silt in the sewer. It is the consensus of opinion of the various workers in the field that H₂S is not generated in rapidly flowing sewage. Heukelekian⁶ found that H₂S will not be produced in sewage until the bacteria have first utilised all the available dissolved oxygen and nitrate. In the rapidly flowing body of sewage, sulphides are not generated, but on the contrary are destroyed by oxygen which is continually being absorbed from the surface. In completely filled sewers the H₂S generation in the flowing sewage is generally found to be negligible.

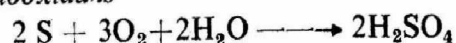
Oxidation of H₂S to Sulphuric Acid

Concrete sewer damage, often attributed to H₂S, is not directly due to H₂S but due to the sulphuric acid generated from it. Hydrogen sulphide is a highly reduced state of sulphur and is readily oxidised by dissolved oxygen or by several bacterial species when oxygen is present⁷. Under sewer conditions where these bacteria are active and corrosion is taking place, their growth requirements are met in the following way. Oxygen, a normal constituent of sewer air, H₂S a necessary pre-requisite for sewer corrosion, and CO₂ are usually present in the sewer air in higher concentration than in the atmosphere. Ammonia, also present due to emission from the sewage, is fixed on the acidic corrosion products.

Sulphur bacteria obtain their energy from the oxidation of H₂S, thiosulphate and other reduced sulphur compounds. Thiosulphates, are preferentially further reduced to HS⁻ion by the sulphur reducing bacteria. H₂S gas (HS⁻ion) is the most important substrate for the sulphur oxidising bacteria. The most important aspect of the most common sulphur oxidising bacteria (*Thiobacillus* sp.) is their ability to survive and function at pH values of 1.0 and below.

The genus *Thiobacillus* contains 9 species. *Thiobacillus* sp. are non-spore forming gram-negative rods which are commonly 1-3 microns long and about 0.5 micron in diameter. Movement in most species is through polar flagella. The following equations typify the transformations catalysed by *Thiobacilli* :

T. thiooxidans



T. thioparus



A possible mechanism of H₂S oxidation is postulated as the reverse of sulphate reduction described earlier.

Acid Attack on Concrete

The third and final stage is the reaction between the sulphuric acid formed by bacterial oxidation of the H₂S in the sewer air with the cement constituents of the concrete ; this is ultimately responsible for the disintegration observed.

The sulphuric acid so produced reacts with the lime in the concrete to form calcium sulphate (gypsum). The calcium sulphate, in turn, reacts with the calcium aluminates in the cement to form calcium sulpho-aluminates. Expansion caused by these reactions results in spalling of the surface of the concrete, thereby exposing underlying layers of concrete to further attack. Even with constant acid formation it is possible that concrete of different mix or cement of different chemical composition will be attacked at different rates under identical conditions in the sewer air. If the corrosion products adhere to the surface of the concrete, a certain measure of protection against further acid attack is provided. The sites of slime formation and that of acid attack are shown in Fig. 1^{7a}

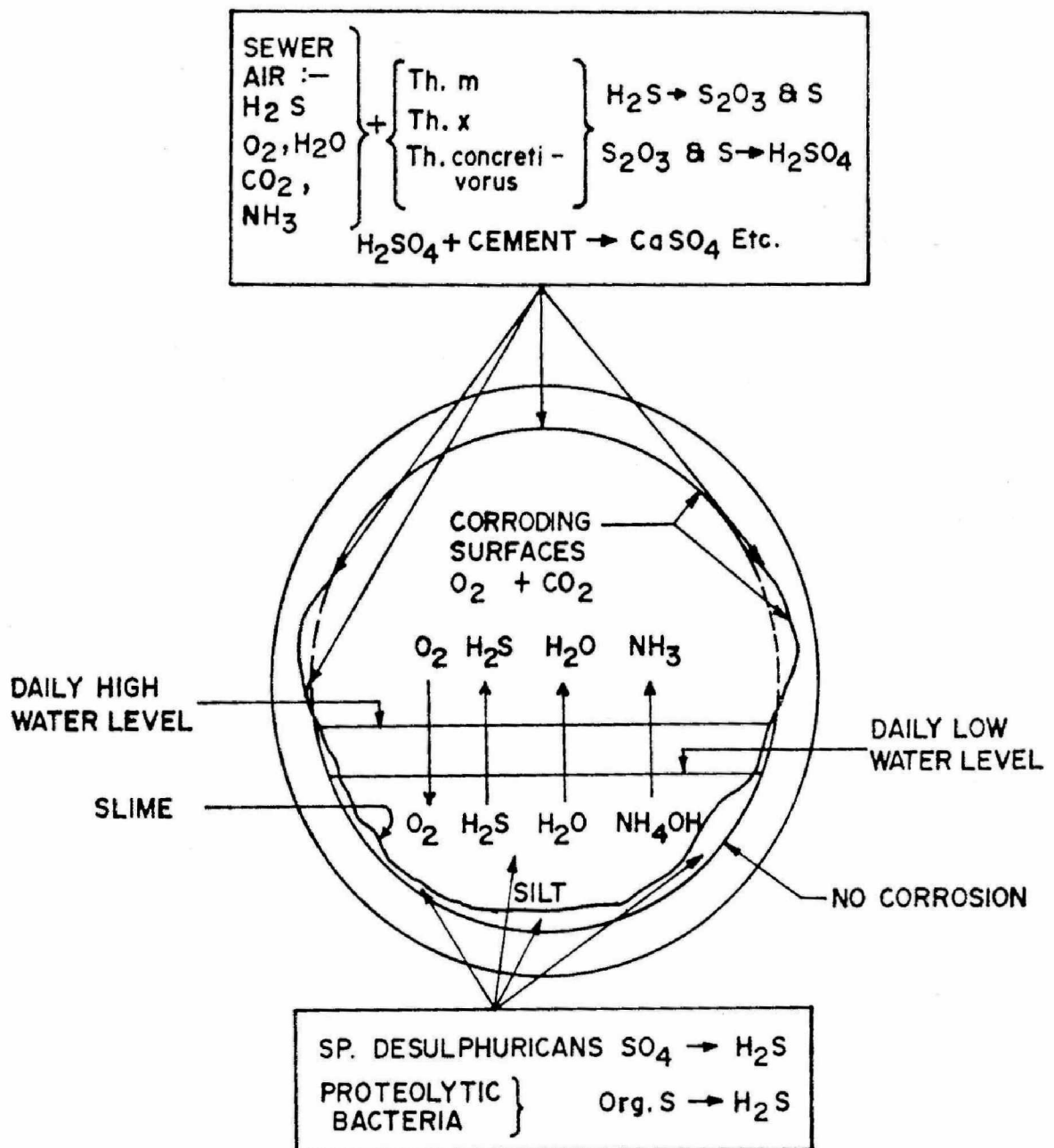


FIG. 1 FACTORS IN BACTERIAL CORROSION OF CONCRETE SEWERS

Sulphuric acid as such does not, and in fact, cannot penetrate into normal concrete because of the latter's considerable reserve of basic constituents. Acid attack, therefore, takes place at the surface, the latter receding as a solution of the basic material (cement, etc.) takes place.⁷ The most outstanding character of this form of corrosion is the fact that it only occurs above the water line. There will be no attack below daily water level and the point of most intense attack is frequently observed just above daily high water level. In the early stages of corrosion the surface of the concrete sewer may develop a fairly dry incrustation which later becomes moist and the surface eventually shows complete disintegration. Chemical analysis reveals a very high concentration of sulphate and the corrosion products are characterised by progressive lowering of pH value with intensification of corrosion. In the final stages of corrosion, the pH value is frequently less than 2.0. Sulphuric acid concentrations in excess of 10% have frequently been measured in the condensate on the soffit of sewers in the City of Los Angeles².

FACTORS INFLUENCING SULPHIDE GENERATION

The factors that influence sulphide generation in sewers include : (i) temperature of sewage, (ii) strength of sewage, (iii) velocity of flow, (iv) age of sewage, (v) pH value of sewage, (vi) sulphate concentration, and (vii) ventilation of the sewer.

Temperature

As sulphide generation is a biological phenomenon it is obvious that sewage temperature influences the rate of sulphide generation. Temperature below 20°C generally will not cause any appreciable sulphide build up. From 20°C up to 30°C, it was found that the rate of sulphide generation increased at about 7% per °C rise in temperature.^{4,5} At 42°C there is an appreciable lag in the rate of generation and this maximum is not as great as at 38°C. At 46° and 52°C, the lag is even more but eventually maximum rates exceeding those at lower temperatures are attained.

Strength of sewage

A high concentration of bacterial nutrients in the sewage will lead to an increased rate of sulphide generation. For any specified sewage temperature and flow condition in a sewer, there is a limiting sewage strength, below which, a build up of hydrogen sulphide will not occur⁴. Even though the BOD test is not ideal for correlation with sulphide generation, it is apparently related to the latter. It was found that hydrogen sulphide generation practically ceased when the BOD of sewage dropped below 80 ppm⁴. This is because aeration at the surface of the stream provides enough oxygen to destroy the sulphide as fast as it is formed when the BOD is below that limiting value. However, it is possible in a long force main or at other locations where oxygen is shut off from the sewage for a few hours, that sulphide build up may occur even with low values of BOD.

Velocity of flow

Velocity of flow is an important factor in the control of hydrogen sulphide. If the velocity of flow is great enough to keep the submerged surfaces of the sewer free from slimes, no generation of H₂S will occur. The minimum velocity above which sulphide build up will not occur would be that when the oxidation by absorbed oxygen is equal to the evolution of H₂S by slimes. Streeter, *et al*⁸. have shown that the rate of absorption of oxygen by a stream varies as the 1.75 power of the velocity. Since both temperature and strength of sewage influence the rate of sulphide generation, they have

been combined for convenience by Pomeroy and Bowlus⁴ into a single term known as 'effective BOD' by the formula,

$$\text{Effective BOD} = \text{Standard BOD} \times (1.07)^{t-20} \text{ where } t \text{ is the temperature in } ^\circ\text{C}.$$

They tabulated the velocities necessary to prevent the build up of sulphides in flowing sewage corresponding to different values of the 'effective BOD'. Values shown in Table 1 agree with the relationship,⁹

$$V = 0.137 \times (\text{Effective BOD})^{0.496}$$

Table 1

Required velocity to prevent sulphide build up⁴

Effective BOD	Velocity, ft. per sec.
55	1.0
125	1.5
225	2.0
350	2.5
500	3.0
690	3.5
900	4.0

In determining the velocity to be used in design, the effective BOD should be calculated for the period of the year which gives the maximum value. Pomeroy and Bowlus⁴ do not claim that the relationship given by them is rigidly true under all conditions, as the BOD alone is not an adequate measure of influence of sewage 'strength' in the sulphide production process.

Davy⁹ has shown that a better fit to observations made in Melbourne sewers is given by relating the Renolds number to 'effective BOD' with another equation of the form

$$N_{Re} = C \left[\frac{A}{b} (\text{BOD}) f(T) \right]^{\frac{1}{n}}$$

in which N_{Re} is the Renolds number, C the constant, A the cross-sectional area of the sewage flow, b the surface width of the flow perpendicular to the direction of flow, BOD the measure of 5-day BOD at 20°C , $f(T)$ the function of temperature expressed in $^\circ\text{C}$ and n the constant. These relationships, even though useful for approximate calculations, suffer from the disadvantage that they do not take into consideration : (i) the age of sewage, (ii) the rate of oxygen solution, and (iii) the presence and amount of trade wastes in domestic sewage. It would appear, therefore, that to establish a relationship with the widest application, further work is necessary.

Recently, Pomeroy⁷ has advanced some relationship which attempts to tie all of these factors

together. The following equation is an expression combining these factors and is being used in design in the Southern California area,

$$Z = \frac{\text{Effective BOD}}{S^{\frac{1}{2}} Q^{\frac{1}{2}} f\left(\frac{d}{D}\right)}$$

where S is the slope in ft. per ft., Q the flow in cusec., d the diameter of pipe in ft., D the depth of flow in ft., and $f\left(\frac{d}{D}\right)$ the function of $\frac{\text{Diameter}}{\text{Depth of flow}}$. The value of $Z < 7,500$ corresponds to the presence of little or no sulphides and $Z > 7,500$ almost always indicates the presence of sulphides.

Pomeroy⁷ has also proposed an expression for the calculation of sulphide generation on submerged surfaces. These are as given below.

Gravity sewers

$$S = E\text{-BOD} \times A \times K$$

where S is the sulphide content in lb. per day, E-BOD the effective BOD in ppm, A the area of submerged surfaces in sq. ft., and K the constant (5×10^{-6}).

Force mains

$$S = K t(E\text{-BOD}) \frac{(1 + 0.01 d)}{d}$$

where S is the sulphide content in ppm, K the constant (0.0026), t the time of passage in min., E-BOD the effective BOD in ppm, and d the diameter of force main in inches.

The equations are based upon the assumption of no absorption of oxygen at the free sewage surface in a gravity sewer. If oxygenation exists, sulphide build up would be less.

As a rule-of-thumb, Pomeroy⁷ showed that in sewers with slime growth (but little bottom sludge) sulphide build up was in the range of 0.3-0.6 lb. per day per 1,000 sq. ft. of slime surface per 100 ppm of effective BOD.

Age of sewage

The oxidation-reduction potential of sewage which is in turn influenced by the age of sewage seems to be one of the important factors contributing to sulphide build up in the lower reaches. When septic sewage is discharged from a collecting system, an Imhoff tank, or from a septic tank into an outfall, it should be treated before it goes into the sewer. When outfall grades are steep, the problem is particularly acute since high turbulence can release the sulphides causing odour and corrosion problems.

Long detention times in forced mains greatly influence the generation of sulphides. As a rule-of-thumb, generation of sulphide within a force main approximates 0.3-0.6 lb. per day per 1,000 sq. ft. of slime surface per 100 ppm of effective BOD. Fortunately, in a majority of cases, sewage is not retained in the system long enough to cause any septic conditions due to age. It should be remembered,

however, that velocity of flow is more important than the length of time the sewage is retained in the system.

Hydrogen ion concentration

Sulphide producing organisms are known to have a considerable adaptability⁴ so that pH value is not likely to have much effect on the rate of generation in sewers within the range of 6-8. If the pH value is above 9.0 or below 5.5, sulphide generation will be affected. However, the amount of sulphide present as H_2S is greatly influenced by the pH value of sewage. For example, at 25°C when the pH value is 6.0, hydrogen sulphide forms 83% of the dissolved sulphide; at pH value 7.0, it is 33%, at pH value 8.0 it is 4.8% and at pH value 9.0, the hydrogen sulphide represents only 0.5%.⁴

Sulphate concentration

High concentration of sulphates and nitrates in the water supplies and their relation to hydrogen sulphide corrosion were reviewed. There is a difference of opinion among the authorities as to the effect of sulphates on the production of hydrogen sulphide. Pomeroy and Bowls⁴ state that sulphate concentration above 50 ppm does not have much effect on the rate of sulphide generation in flowing sewers. In bottle experiments, the rate of sulphide generation with an initial sulphate concentration of 1,000 ppm was not very much more than that for 89 ppm in up to 250 hr. of incubation. It is believed that concentrations over about 50 ppm are not a substantial factor in flowing sewers. For conditions, such as, anaerobic sludge digestion where detention periods are long, an increase in the sulphates can substantially increase the hydrogen sulphide in the gas. Apparently in an active anaerobic environment of this sort, the organisms will extract their oxygen from the first substrate they come in contact with. The more the presence of sulphate, the more is its reduction to H_2S .

Ventilation

Ample ventilation through sewers will help in carrying away the generated H_2S , supply additional oxygen to the sewage and keep the walls free of moisture and reduce the tendency for sulphuric acid formation and attack of concrete. Ventilation is particularly important in locations of turbulent flow. Either by better natural ventilation or by forced ventilation by fans, one or more of the necessary factors for optimal bacterial activity can be made limiting. The experiments of the City of Los Angeles with sewer ventilation have been described by Studley¹⁰ and Smith.¹¹ Tests during the summer of 1940 at the station in Los Angeles which was ventilating 4 miles of 10 ft. sewer showed the removal of 60 lb. per day of H_2S with the vented air, which otherwise would have formed 170 lb. per day of sulphuric acid. It is often very difficult and expensive to provide enough ventilation to achieve drying and for oxidation sufficient to prevent corrosion. In addition, discharge of a larger volume of withdrawn sewer atmosphere at a single point often introduces a severe odour control problem. Incineration is used by some agencies (San Diego, Pittsburgh) but all of the withdrawn atmosphere must be heated to about 1,400°F. and held at that temperature for 3-5 sec.

The area of biologically active surface has also great influence on sulphide generation. It has already been mentioned that for an 'effective BOD' of 100 ppm and at a temperature of 20°C, the rate of sulphide production was found to be 0.3-0.6 lb. per day per 1,000 sq. ft. of active slime surface⁴.

In large sewers the amount of sulphide escaping to the atmosphere is usually very small compared to the amount carried by the sewage. The factors influencing the rate of emission of H_2S include the

following : (i) the concentration of undissociated hydrogen sulphide in the sewage film at the surface, which in turn is determined by the total sulphide content, pH value and the absence of heavy metal ions, (ii) the thickness of the thin 'laminar' layers in sewage and air adjoining the sewage-air interface, (iii) the presence of floating or absorbed surface films on the sewage surface which cause resistance to passage of sulphides between phases.

SULPHIDE CONTROL PROCEDURES

The following are some of the criteria that may be taken into account in preventing or controlling sulphide build up and consequent odour and/or corrosion.

Design of sewers

In the design of sewer systems, consideration should be given to the desirability of maintaining velocities sufficient to avoid sulphide build up and of minimising pressure lines and points of high turbulence. In designing sewerage systems, all the contributing factors should be thoroughly considered. The Pomeroy and Bowlus theory⁴ with its recent modifications will be useful in designing sewers wherein the probability of sulphide build up will be least. The designer should take into consideration topography, grades of sewers, ventilation, materials of construction, sewage temperature and strengths, etc.

Some of the design features which should be considered are as follows: one of the important factors in the control of H_2S is velocity of flow. The limiting velocities for prevention of sulphide generation vary with temperature and effective BOD (Table 1). The velocities given in Table 1 are believed to be the minimum that should be used. An allowance of 25% in the velocity should be made as a factor of safety and if industrial wastes are present with a higher content of dissolved organic matter, it may be necessary to increase this allowance to 50%. Where it is impractical to provide a sewer gradient in design to give these limiting velocities, other means of controlling sulphide generation should be considered. Velocities giving high single point turbulence may, however, result in sulphide release and severe odour and/or corrosion.

Concrete for sewers should be of high quality. For plastic mixes, this means a low water-cement ratio of suitable workability, thorough mixing, proper placing and sufficient curing¹⁴.

Except in the cases where sewage is quite weak and in a fairly well aerated condition, high sulphide generation because of large slime areas can be expected in completely filled lines. Force mains, therefore, should be kept to a minimum.

Turbulence caused by high velocities for short distances or improper design of junction manholes permitting sewage lines to intersect at right angles or at different elevations should be avoided as turbulence can cause excessive release of H_2S even where sewage contains only a small amount of dissolved sulphides.

Control of sewage character

Trade wastes containing dissolved sulphides should not be allowed into the sewers. High sulphate concentrations arising from the discharge of tidal or sea water to the sewer should be controlled. The oxidation-reduction potential of the sewage can be increased and the rate of generation of H_2S

slowed down by steps which include the partial purification of sewage allowed into the sewers by sedimentation or by high rate treatment on filters. 'Effective BOD' of sewage depends upon sewage strength and temperature. By reducing sewage strength and/or temperature, 'effective BOD' as well as minimum velocity required can be reduced. Strength of sewage can be reduced in some cases by diluting sewage with unpolluted water. It must be realised, however, that dilution reduces the wastes carrying capacity of the sewer.

Where velocities are inadequate to control the formation of H_2S or where completely filled lines are encountered as in force mains, supplemental aeration by the use of compressed air may be desirable. Pomeroy¹² described the technique of sulphide control by air injection. His studies indicated that in most cases air injection would prevent hydrogen sulphide building up and in any case will greatly reduce generation. Air addition at about 1 c. ft. per min. per in. of inside sewer diameter is necessary. Care must be taken to prevent the formation of air pockets in such lines, since experience has shown that some H_2S will form on the walls at the points of such air pockets and corrosion will occur.

Cleaning of sewers

Removal of slime and silts has the effect of reducing the sulphide generation. Periodic cleaning of sewers by mechanical or chemical means is necessary. Any partial blocking of the sewer by debris will result in retardation of flow and consequent anaerobic decomposition of deposited sludge. Periodic mechanical cleaning and flushing of sewers can reduce average sulphide generation by 50%. *A good continuing programme of mechanical cleaning is probably the basic foundation for any control programme.*

Sulphuric acid is effective in reducing slimes. Intermittent use of sulphuric acid was found to be useful in removing slimes on the submerged walls. Tests have indicated that the lowering of pH value to around 3.5 for a couple of hours reduced total sulphides from about 15 to less than 1 ppm⁴. Caution must be exercised in the use of sulphuric acid for this purpose, as, on acidification, iron sulphide, that may be present on sewer walls, may cause a sufficient initial release of H_2S sufficient to be fatal to any workmen in the sewer. The shift of pH value also changes all the ionised sulphide (in the flow) to H_2S .

Slaked lime, $Ca(OH)_2$, is probably a more suitable chemical for chemically treating slime since no corrosion damage will result from it and sulphide release will not occur. It has been found that if the slimes are subject to a lime slurry of about 8,000 ppm for 45 min. they will be inactivated for periods of from 3-14 days depending upon flow and sewage characteristics.

Use of chemicals

Many chemicals can be used for suppressing the biological activity which is necessary for H_2S production. Chlorine has been successfully used in controlling sulphide generation for many years. Chlorine is effective in three ways ; (i) it destroys sulphides by chemical reaction, (ii) it reduces biological activity and produces mild oxidising compounds in the sewage, and (iii) it destroys the slimes. The ratio of chlorine applied to sulphide destroyed is about 9 to 1, but in practical application an excess is required to meet peak requirements.¹³ When excess chlorine is applied, it leaves the sewage in an oxidised state, and prevents the re-appearance of sulphide for some distance downstream.

The addition of salts of copper, iron or zinc to the sewage has the effect of precipitating sulphides

of these metals thereby preventing emission of H_2S into sewer air. Of these, ferrous, ferric and zinc salts have been extensively studied.

If the pH value of sewage is increased to above 8.5, H_2S in sewage will be more dissociated resulting in reducing the rate of emission of H_2S into the sewer atmosphere.

Where ponding conditions exist, nitrates have been useful in sulphide control. The cost of nitrate treatment is generally high.

MATERIALS OF CONSTRUCTION

Resistant concrete

It is possible that supersulphated metallurgical cement, pozzolan-portland, cement mixtures or portland cement low in tricalcium aluminate may be more resistant to attack than normal portland cement. The relationship between the composition of concrete and acid attack has been most extensively studied.^{14, 15} A specimen prepared with water-cement ratio of 0.60 failed more rapidly than specimens with ratios of 0.35 and 0.45. Aluminous cement (*Ciment Fondu*) has initial resistance to acid attack. Its corrosion products are also not extensive. So it may have some use in sewer structures.

Protection of sewer structures by lining or coating against H_2S attack can also be considered if other methods of control are impracticable.

Liners

A plastic polyvinyl chloride sheet, termed 'Amerplate' is one of the successful lining materials attempted in USA. rtrified clay of low porosity has also been used as a liner. In regions where high sulphides and high production of H_2SO_4 can be expected problems still remain. Clay of sufficient impermeability has not been prepared and jointing remains a weak point. Cement mortar joints are subject to attack. Bituminous joints are emulsified and dissolved by soaps, oils and greases. Acid proof cement joints offer the best protection but they are costly. Some types of plastic coatings and/or linings for sewers and other structures have proved moderately successful, given continued inspection and maintenance. The function of these linings is to isolate the concrete from the corrosive atmosphere.

Protective coatings

Any protective coating used should possess the following qualities: (i) it should be resistant to acid attack, (ii) it should bond securely to the concrete, (iii) it should be economical and durable, (iv) it should be resistant to abrasive action by flow of sewage, and (v) when applied, it should be thin enough to fill all pores and irregularities in the surface. That the coating should be continuous with no pin holes or other breaks.

The effectiveness of a coating thus depends on its inherent resistance to acid attack but also on its ability to form impervious membrane. In practice, no coating can be applied without discontinuity. Inspection and maintenance must be relatively continuous. Among painted coatings, good performance was reported for a plastic-base paint.¹⁶ Coal tar epoxy coatings have also proved to be excellent performers for this use.

CONCLUSIONS

It can be seen that the problem of sewer corrosion due to hydrogen sulphide production and its control is a serious one to the waste conveyance system. It is particularly acute in areas of the world

where sewage strengths are high, where sulphate content of the waters is substantial and where average temperatures are above 20°C. Some basic research has explored some of the problems ; but much remains to be done. Prevention of H₂S generation by proper design and a continued cleaning of sewers seems to be the best available methods.

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MR. L. P. BORKAR (Bombay Municipal Corporation, Bombay)

As regards the corrosion of concrete, it has been our biggest problem and still remains one. Mainly the failures have been in sewers and as a matter of fact we are at this time replacing a good length of the pipes. As told by Dr. Mohanrao corrosion can be reduced by either ventilation or by allowing the sewer to run surcharged so that whatever sulphuric acid that is formed, gets washed off. But latter method can be applied in storm drains only because at all times it is difficult to assure that the sewers will remain full. It seems that using acid resistant lining is the only solution. Though ventilation is a good solution it is generally difficult to keep the ventilation system constantly in good condition. As a matter of fact under ordinary condition the best method may be to allow sewer surcharge once in two hours and forget about it.

In connection with the corrosion of sewers, the main problem is that the sewers are designed for a velocity of 3-4 feet which should be sufficient to keep the sedimentation low. However, even when the sewers are running at full velocity of 1 foot or 2 feet sedimentation is obtained which does not make much difference. Our greatest trouble is at the interface of the sewage and air. The method we are adopting is just to get it replaced after every 10 years. I would, however, like to have suggestions regarding some other methods which can be economically adopted.

As regards corrosion in primary sedimentation tanks, we have not faced any serious problems in Bombay. I would, however, like to know from Mr. Purohit how far cathodic protection can be of help in effective prevention of this type of corrosion.

MR. V. T. PUROHIT (Electro Corr-Damp, Bombay)

As regards the concrete we never instst increasing the density of the concrete. Even if there is H_2S formation, the RCC does not undergo any corrosion so long it remains submerged. The trouble comes only when it is in contact with the gas.

MR. A. RAMAN (Public Health Engineering Department, Tamil Nadu)

We have observed considerable amount of corrosion in concrete sewers in Madras city. The city sewers have developed high concentration of sulphides due to the presence of good amount of sulphates in the water, high temperature and long length of travel in the sewers. We have, therefore, found it prudent to use cast iron pipes of 18" dia instead of RCC. However, this doubles the cost of sewers.

It has been suggested in Dr. Mohanrao's paper that by designing the sewers for adequate velocity we could protect against sulphide attack to some extent. But we have not only to consider the ultimate designed velocity but also the designed velocities in early stages. Many other methods have also been suggested for protection of concrete sewers and incidentally the most promising one would be some protective coating, like, the epoxy. I would very much like to know the cost of epoxy lining.

MR. K. S. RAO (CIBA, Bombay)

Referring to Mr. Raman's question, the cost of coal-tar epoxy would come to about Rs. 20-30/sq. m. which for pure epoxy will be about Rs. 30-40/sq. m.

MR. S. R. RANE (Bombay Municipal Corporation, Bombay)

Corrosion has been one of the serious problems for our sewage treatment plants in Bombay. The factors affecting corrosion dealt with by the different speakers and participants, will be of considerable help in planning out suitable preventive measures in future.