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SUSTAINABILITY OF WATER AND SANITATION SYSTEMS

Increasing sewer longevity by septicity control

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SEPTICITY WITHIN A sewerage system occurs when micro-organisms present in sewage and adhering to submerged surfaces have utilised all the dissolved oxygen and any nitrates that may be present in the sewage (derived from ground-water infiltration or present in the water supply). When anaerobic conditions have developed, bacteria in the sewage reduce the organic compounds of sulphur to sulphide and subsequently the sulphate-reducing bacteria utilise sulphates, as an alternative electron acceptor for the dissimilation of organic matter, and form sulphides. The consequences of sewage septicity are important for two critical reasons:

1) The formation of noxious odours which can give rise to a public nuisance; and

2) The corrosion of the fabric of the sewerage system by hydrogen sulphide including its biological oxidation to sulphuric acid which can result in the complete destruction of concrete pipes and mortar joints, particularly in warm climates where rates of sulphide formation and oxidation will be very high.

Sewage by its nature has an unpleasant odour which is made obnoxious when it becomes septic. Typical compounds present in odours from sewage include: organic sulphides and H_2S with odour thresholds within the range 1 to 4 ppb (these are acidic odours); and ammonia and amines (including other organic compounds such as skatole, indole and diethylamine) which have much higher odour thresholds than the acidic sulphides but are more persistent (these are alkaline odours).

Problems of odour and corrosion which can arise from sulphide formation will depend on the amount of hydrogen sulphide which escapes into the sewer atmosphere, and this will depend on the pH value of the sewage.

Hydrogen sulphide is a flammable and very poisonous gas with a characteristic odour of rotten eggs. Its threshold odour concentration is very low - between 1 and 10 ng/l - and it is potentially very dangerous because its smell is quickly lost as the concentration increases; unconsciousness followed by death can occur suddenly from about 300 ppm by volume in air. It can transfer into the sewer atmosphere where sewage turbulence occurs, for example in wet-wells, back drops, manholes and in gravity sewers. Its smell is made worse by the presence of other malodorous compounds, particularly mercaptans (or thiols) which may be formed in anaerobic sewage.

H_2S corrodes copper, copper-based alloys such as brass, some bronzes and Monel metal and silver to form black metal sulphides. As a result, it can have a disastrous effect on electrical equipment at pumping stations. Metalwork, such as step-irons, ladders, manhole covers and penstocks, unless made of corrosion-resistant materials, will be destroyed by prolonged exposure to hydrogen sulphide particularly in damp conditions. Even cast-iron and some grades of stainless steel will be corroded (or pitted).

It is, however, through the corrosion of concrete sewers, manholes, and Portland cement mortar by the acidic products of H_2S oxidation that the prime consequence of septicity is well known. If oxidation occurs while H_2S is dissolved in sewage the products are harmless. At pH values between 6 and 7, chemical oxidation in sewage produces sulphur, while at higher pH values (between 7 and 9) dissolved H_2S would be oxidized to sulphourous compounds and finally to sulphate. However, H_2S in the damp, warm atmosphere within a gravity sewer, manhole, or wet-well will be oxidized to sulphuric acid by various autotrophic thiobacilli which grow successfully on exposed walls and other surfaces.

Problems associated with corrosion (and odour) caused by septicity occur in many parts of the world and particularly where sewage temperatures are high. Total collapse of eight-year old concrete and asbestos-cement sewers has been recorded in South Africa, and concrete sewers have failed after only six years in the Middle East. However, problems also exist in temperate climates as well.

In nearly all cases cited in the literature, the effect of septicity has been most serious downstream from rising-main sewers, in locations where debris can accumulate, and in circumstances where excessive turbulence (back-drop, cascades, inverted siphons etc) allows previously formed H_2S to be emitted into the atmosphere.

Gravity sewers should be designed to ensure that self-cleansing velocities are maintained at average flow-rates and that debris deposited at lower flow-rates will be eroded in order to prevent excessive accumulation. If such debris were retained within the sewerage system for long periods between peak flow-rates it would inevitably result in sulphide formation within the sediments which could cause odour and corrosion problems. A self-cleansing velocity of about 0.75 m/s should be adequate to keep sewage aerobic and this should prevent sulphide formation within the sewage but may not completely avoid sulphide being formed in accumulated debris and released as H_2S at points of turbulence.

When sewage is pumped up a rising-main sewer, out of contact with the atmosphere, the dissolved oxygen which may be initially present will be rapidly used by microbial activity and sulphide formation will start. The effect of temperature on the formation of sulphide (i.e. the rate of formation should double when the temperature increases by 10°C within the range 5-25°C)

Prevention of septicity

Inhibition

It is possible to inhibit the activity of the micro-organisms responsible for sulphide formation by addition of bactericidal chemicals. Such chemicals include chlorine, sodium hypochlorite or a range of organic chemicals (mostly chlorinated hydrocarbons) which would need to be added continuously in order to remain effective and may require high dose rates. The high cost of such continuous additions, together with possibility of problems with biological treatment processes downstream (particularly anaerobic digestion of sludges) caused by residual chemicals or byproducts, are likely to preclude the widespread use of such bactericidal chemicals for total prevention of sulphide formation.

Maintaining Aerobic Conditions

Sulphide will not be formed in sewage if dissolved oxygen (DO) is present. In a rising-main sewer, sewage is kept out of contact with the atmosphere and soon becomes anaerobic, particularly in small-diameter pipes with a large internal surface area per unit volume. Injection of air into sewage entering a rising-main can be used to reduce the period for which anaerobic conditions may develop and hence minimize sulphide formation. Use of commercial oxygen allows the saturation concentration of DO to be increased about five-fold, and potential problems associated with residual nitrogen gas can be avoided.

Maintaining Anoxic Conditions

In the absence of dissolved oxygen, nitrate can be an alternative to sulphate (as an electron acceptor) for dissimilation of organic matter, as the bacteria involved function at a higher redox potential than the proteolytic bacteria (which reduce organic sulphur) and sulphate-reducing bacteria. The condition under which micro-organisms utilise nitrate for the dissimilation of organic matter in sewage is termed anoxic. In recent years, various proprietary chemicals, which contain nitrate, have been used to prevent sulphide formation in rising-main sewers in the UK. Some of these chemicals contain an oxidised iron salt (Iron(III) sulphate) and nitric acid, and will be effective provided that the nitrate is not totally used by the micro-organisms. However, when the nitrate has been used by the micro-organisms, septicity will recur (enhanced in rate by added iron ions) and Iron(II) salts will be formed which are corrosive to steel, copper, brass, bronze, zinc and silver. The sulphate anion of the added Iron(III) salt will also be available for reduction to sulphide, so the overall effect may be to increase odours and cause greater corrosion particularly at the end of a long rising-main.

For nitrate addition to prevent completely sulphide formation, it is necessary to calculate how much will be required and this will vary according to the following characteristics of the sewage: Oxygen demand (including slimes growing on the walls); Temperature; and Flow-rate of sewage (which will vary between night and day and also dry and wet weather).

Chemicals to remove H_2S

Addition of lime (or preferably sodium hydroxide) to increase the pH value of sewage, and so reduce the proportion of sulphide present as H_2S, will reduce the emission of H_2S and can inhibit bacterial action. Alkali addition, to increase the pH value above 9 at all times, would probably be more expensive, and difficult to control effectively, than available alternatives. It would also result in release of alkaline odours which could cause odour nuisance. However, in some cases, such as small-diameter rising-mains, in which sewage is retained for long periods (possibly greater than 18 h), the cost of alkali might be similar to oxygen injection, chlorination, or the addition of other chemicals such as hydrogen peroxide, nitrate salts or bactericides.

An alternative to oxygen injection into sewage entering a rising-main would be to inject oxygen into sewage before it leaves the discharge end of a main and so oxidize previously-formed sulphide. Such a method could be used where sewage was pumped infrequently into a rising-main thus resulting in long retention periods. A simple system would involve recirculation of sewage contained in a relatively short length of the main near to its discharge end. A small pump would be need to operate continuously and capable of recirculating several times the sewage contained in the short length of main, both during the period that sewage was being pumped along the main and when it was stationary.

Mathematical modelling to control odours and minimise corrosion (SPACA)

The need to prevent and control septicity of an entire sewerage system, which may contain numerous gravity and rising-main sewers, may be complex with preventative actions taken upstream having an effect on odour formation and release downstream. In order to provide an effective logical and systematic approach. Acer have produced a computer-based mathematical model, consisting of Septicity Prediction And Control Algorithms (SPACA), which will estimate sulphide production and concentration throughout a network of sewers (either existing or proposed) in order to develop a strategy for sulphide prevention. The model can be used to assess the effectiveness of various methods of control, including oxygen injection, or the addition of nitrate, chlorine or hypochlorite, hydrogen peroxide or iron salts. This allows the establishment of a least-cost option, to provide an effective resolution to potential or existing odour problems over a wide range of operating conditions. Inputs to the model include sewage flow-rate, temperature, COD, pH value, respiration rates, dissolved oxygen, sulphate and sulphide concentrations as well as sewer sizes, including lengths and types (gravity or rising-main).

The mathematical model utilises empirical equations. The computer programme is Windows based and written in Visual Basic which ensures excellent user interface, rapid calculation and good presentation of results. In order to reduce the complexity of the model, it runs under steady-state conditions. To enable the effects of diurnal flow variation in the sewerage system to be taken into account, model runs can be performed on the system at a number of flow conditions which allows a sensitivity analysis to be carried out.

The sewerage network is represented by a number of “nodes” and connecting “sewer-pipes”. Each significant junction between sewers in the system can be represented by a node. All pumping stations, manholes at sewer intersections, or changes between gravity and pumping mains, are included into the model network as well as the final treatment works. Each connecting pipe must be specified as gravity or rising main and have its physical parameters (diameter, length and gradient) defined. Each node has its position in the network defined (at the periphery, middle or ultimate end) and the necessary information on flow, temperature, respiration rate and composition of sewage entered, or calculated, to enable sulphide production to be estimated.

It would be unrealistic and uneconomic to attempt to limit sulphide production to zero at all times, in all conditions. Sulphide concentrations can be tolerated in sewage if corrosion is not accentuated and odour nuisance does not occur. The required level of control of sulphide formation was based on two factors, firstly levels required to avoid corrosion and secondly levels required to avoid odour nuisance. a) Corrosion - sulphide levels above 1 mg / l are likely to be a problem with respect to corrosion, although corrosion has been known to occur at concentrations of 0.5 mg / l in turbulent conditions[5]. Sulphide concentrations were therefore controlled so that they should not exceed 0.5 mg / l at any time. b) Odour nuisance can be estimated by calculating the odour radius resulting from release of H_2S. The odour radius gives the estimated area from the odour source within which odour complaints could be expected.

Running the model

Once an adequate calibration is achieved, results can be analysed to highlight the sites which require immediately treatment and those which require no, or minimal, action. The model output shows both sulphide concentrations in the sewage and sulphide production rates in each pipe. Control measures, such as addition of oxygen, nitrate or other chemicals, can be activated at every node and the quantity introduced into the system to prevent sulphide production can be user-specified or automatically calculated. Implementing only one treatment measure at a time allowed analysis of the impact that each would make to the system as a whole and so to build up a step-by-step control strategy which was both effective and economic.

In conclusion It should be emphasised that there is no single simple solution to sewage septicity, which can give rise to the need for odour control and the prevention of corrosion within a sewerage system or at a treatment works, because no two systems are alike. It is necessary therefore to examine fully the causes of septicity, prior to taking any action to prevent or control its formation. In most circumstances, this may be done using data and equations available from the literature, although there is no substitute for obtaining recent data from the system to be investigated.

Prevention of septicity by oxygen injection, nitrate addition or adequate aeration within the sewerage system is likely in many cases to be more economic and effective than to add chemicals to remove sulphide after formation, particularly such prevention it will result in partial treatment of the sewage. Such pretreatment can have significant benefits of reduced capital and operational costs for the treatment works downstream.

To reduce the operating costs for chemical addition to sewage, it may be possible to use waste industrial effluents which contain the appropriate chemicals, such as nitrates from meat preservation, sodium hydroxide from the textile industry and iron salts from steel manufacture or from steel products. Care would need to be taken to avoid introduction of wastewaters which could be harmful either to the fabric of the sewerage system, to the downstream sewage treatment works, to the receiving water quality or to the operations staff involved.

Because the complete assessment of the consequences of septicity within a sewerage system may be complex, Acer has developed a mathematical model to enable such assessment to be carried out systematically. The results of such a mathematical assessment should enable potential problems of odours and corrosion to be minimised, or avoided, at minimum cost using effective measures of prevention and control that have been outlined in this paper.

Controlling septicity in the rising main can also be a form of treatment where soluble BOD is converted into sludge (insoluble SS), particularly at higher temperatures. Table 1 and 2 show results of such trials for comparison. This illustrates that at higher temperatures with particularly oxygen injection, a high % reduction in BOD is achievable, which in some cases could eliminate the need for secondary treatment altogether. It should be emphasised that such a system will not nitrify or remove phosphorous and if higher degree of treatment is required secondary and / or tertiary treatment may be necessary.

Table 1. Treatment of sewage in the rising main.

Table 2. Primary sedimentation tanks.