



## Mitigation strategies of hydrogen sulphide emission in sewer networks – A review



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### ABSTRACT

Hydrogen sulphide (H<sub>2</sub>S) gas emission in sewer networks is associated with several problems including the release of dangerous odour to the atmosphere and sewer pipe corrosion. The release of odour can endanger public health and corrode sewer pipe walls. Sewer corrosion has the potential to cost water utilities millions of dollars to maintain and rehabilitate the affected sewer pipes. Some chemical mitigation strategies to control hydrogen sulphide emission have been introduced. These include but are not limited to the injection of oxygen, magnesium and sodium hydroxide, calcium nitrate and iron salts. The optimisation of the dosing rate and location of each chemical mitigation strategy is required to achieve maximum hydrogen sulphide gas removal efficiency along with cost effectiveness. In this review paper, the five most popular chemical mitigation strategies that were previously mentioned have been investigated and discussed. The article is broken down into three main discussions. Firstly the sewer transformation processes and factors affecting the hydrogen sulphide generation and emission are highlighted. Secondly, comparisons and differences between each selected chemical mitigation strategy as well as its application covered. Finally, the review of the chemical efficiency and cost is conducted by comparing two case studies in controlling the formation of dissolved sulphide. It was found that the injection of oxygen is the cheapest mitigation strategy of hydrogen sulphide gas generation in sewers, but least effective.

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## 1. Introduction

In addition to being a collection and transportation system, a sewer network can also be considered a reactor for transformation of wastewater due to the presence of substances with pronounced chemical and biological reactivity (Hvitved-Jacobsen et al., 2013). One such biotransformation of wastewater which can cause serious problems for wastewater authorities is the reduction of oxidized sulphur under anaerobic sewer conditions, which leads to the generation and release of hydrogen sulphide gas (Gutierrez et al., 2008). Hydrogen sulphide gas is a serious health hazard for humans and a malodorous compound that can create extreme corrosion problems in the sewer network. Every year sewer workers are injured due to exposure to toxic/lethal levels of

hydrogen sulphide gas (Nielsen et al., 2008b). In terms of health effects, hydrogen sulphide gas will be a nuisance at concentration above 0.0001 ppm. It gives unpleasant smell at concentrations above 0.5 ppm; above 10 ppm it will cause irritation and nausea and above 50 ppm respiratory and eye injuries will occur. At a concentration of 50 ppm, the nuisance will not be detected by human sense but the lethal effects will still exist. Hydrogen sulphide concentration above 50 ppm will be life threatening and at above 700 ppm it will be fatal. For corrosion problem, study from Hvitved-Jacobsen et al. (2002a) has identified the concentration of total sulphide within the range of 0.1–0.5 mg S/L has triggered minor problems of concrete corrosion while severe concrete corrosion may occur at sulphide concentrations from 2.0 mg S/L.

Total sulphide in the wastewater can be classified as: the precipitate of metallic sulphide and the dissolved sulphide species (H<sub>2</sub>S, HS<sup>-</sup> and S<sup>2-</sup>). The presence of dissolved sulphide species in wastewater depends on pH. Only hydrogen sulphide (H<sub>2</sub>S) can be further released to sewer atmosphere (Yongsiri et al., 2003). The generation of dissolved sulphide is as a result of physical, chemical

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and biological processes which mostly take place in anaerobic condition. Dissolved sulphide which has been formed in the anaerobic sewer can be released to sewer atmosphere if the supporting factors such as low flow and high temperature are prevailed. Dissolved sulphide generation can be suppressed by keeping a sewer under aerobic conditions. Under this condition, oxygen will act as electron acceptor and the conversion of organic matters will produce carbon dioxide gas ( $\text{CO}_2$ ) and biomass. In the presence of oxygen, the existing dissolved sulphide that is produced in the deep layer of the sediment and biofilm will be oxidized into sulphate ( $\text{SO}_4^{2-}$ ) and elemental sulphur (Nielsen et al., 2003). This alteration to the sewers conditions (anaerobic to aerobic condition or vice versa) highlights the fact that a sewer is not just a collection and conveyance system but also a process reactor that is an integral part of the entire wastewater system (Hvitved-Jacobsen et al., 2013). In order to control the release of hydrogen sulphide gas, it is common practice among water authorities to dose problematic sewers with chemicals to manipulate the sewer conditions. The manipulation can be intended to inhibit the production of dissolved sulphide or eliminate the hydrogen sulphide ( $\text{H}_2\text{S}$ ) so that it will not be released as hydrogen sulphide gas. A recent survey (Ganigue et al., 2011) identified that there are five chemicals that are used by the Australian water industry to control the hydrogen sulphide gas generation, namely oxygen, nitrate, magnesium hydroxide, sodium hydroxide and iron salts.

The most recent government guidelines on odour and corrosion control in sewers in Australia was prepared in 1989, titled "Hydrogen Sulphide Control Manual" (MMBW, 1989). Since then several advances have been made in the research and development of methods to prevent and/or reduce the generation of hydrogen sulphide in sewer networks. The problem with these method developments is that no single solution has been determined as the best option. Therefore, this review focuses on the application of chemical mitigation strategies to suppress the hydrogen sulphide emission on sewer network. The additional review of cost effectiveness and efficiency of each chemical is also presented in this paper. It is expected that this review paper will reveal the feasibility of implementing chemical mitigation strategy.

## 2. Sewer processes

As have been mentioned in the previous section, the generation of hydrogen sulphide in sewer network is caused by the physical, chemical and biological properties of sewage constituent. There are five main processes which could occur in sewers: (1) generation of dissolved sulphide, (2) emission of hydrogen sulphide, (3) chemical and biological oxidation of dissolved sulphide, (4) precipitation of metallic sulphides and (5) corrosion (Nielsen et al., 2008a). These sewer processes can occur in one or more of the following five phases (Hvitved-Jacobsen et al., 1998) as depicted in Fig. 1 and explained below:

1. *The Sewer Atmosphere*: The confined air-space (gas phase) that exists in partially full gravity sewer pipes which are often referred to as the breeding ground for microbial and chemical processes in sewers.
2. *The Sewer Wall*: The wastewater velocity and shear stress at the walls of the sewer affects build-up of both the sewer biofilm and sediments.
3. *The Biofilm (often named slime)*: A concentrated layer of microorganisms that adheres to all surfaces exposed to water phase in a sewer.
4. *The Sewer Sediments*: Permanent deposits that have settled in combined sewer networks under dry weather conditions (low flow and velocity).

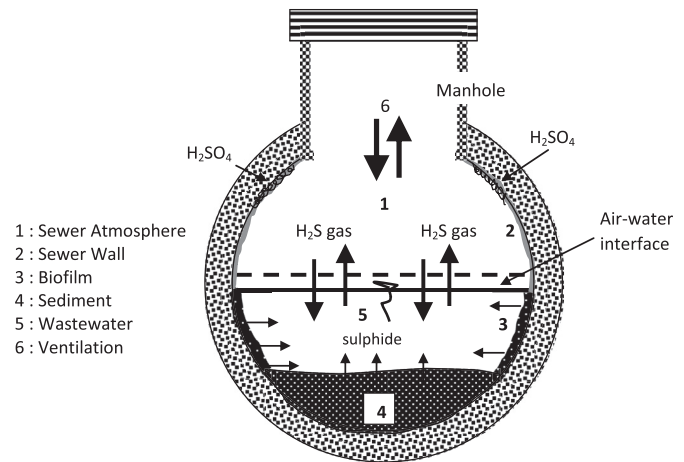


Fig. 1. Illustration of  $\text{H}_2\text{S}$  gas generation process in a partially full sewer.

5. *The Bulk Water*: The sewage (sewer wastewater) which contains organic matter, nutrients, heavy metals, organic micro pollutants and both pathogenic and non-pathogenic microorganisms.

Dissolved sulphide in sewer networks originates primarily from sulphate reduction taking place within anaerobic regions of the biofilm and sediments covering permanently the sewer walls (Norsker et al., 1995; Nielsen et al., 1998). The formed dissolved sulphide will be slowly diffused to the wastewater phase. The chemical and biological oxidation could happen if there is electron acceptor such as oxygen or nitrate in the wastewater phase. The dissolved sulphide oxidation converts the dissolved sulphide back to sulphate and elemental sulphide form (Nielsen et al., 2003, 2006, 2005b). In the presence of metal (primarily iron, zinc and copper), the dissolved sulphide in the wastewater will react with metallic compound to form metallic sulphide that precipitates in the sewer bottom (Nielsen et al., 2005a). If the oxidation and precipitation occurred in the sewer, there will be less chance for the dissolved sulphide to be released to sewer atmosphere and causing problem of odour and corrosion.

The sewer conditions (aerobic, anoxic and anaerobic) present within the five mentioned sewer phases will determine which chemical and biological processes occurred in sewer. The conditions for reduction and oxidation of substances (the redox conditions) play a central role when considering the sewer as a chemical and biological reactor (Hvitved-Jacobsen et al., 2013). Redox reactions involve transferring electrons from one compound to another compound at an atomic or molecular scale. This electron transfer will then initiate oxidation and reduction of the involved compounds. The most important of these electron acceptors in sewer systems are dissolved oxygen ( $\text{O}_2$ ), nitrate ( $\text{NO}_3^-$ ) and sulphate ( $\text{SO}_4^{2-}$ ). These electron acceptors are central for determining which of the following sewer system processes are prevalent:

1. *Aerobic*: An excess of dissolved oxygen in the wastewater will result in the transfer of electrons and reduction of the central element ( $\text{O}_2$ ) which will in turn generate water ( $\text{H}_2\text{O}$ ).
2. *Anoxic*: Requires the absence of dissolved oxygen and the availability of nitrate ( $\text{NO}_3^-$ ) as an electron acceptor for the microbial process. The concentration level of nitrate in wastewater is typically low ( $0\text{--}0.5\text{ g N/m}^3$ ) and as such anoxic conditions are extremely uncommon in sewer systems.
3. *Anaerobic*: The prevalence of sulphate at the upper end of wastewater collection systems (and lack thereof dissolved oxygen) will result in the generation of dissolved sulphide species.

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