Control of sulphide problems in pressure sewers

Contrôle des problèmes de sulfures en conduites forcées

F. Bertrán de Lis, E. Saracevic, N. Matsché

Institute for Water Quality, Resources and Waste Management
Vienna University of Technology
A - 1040 Vienna, Karlsplatz 13/E 226, Austria.
erni@iwag.tuwien.ac.at

RESUME

Le transport des eaux usées par conduites forcées pose un certain nombre de problème du fait de la production de sulfures par des bactéries réduisant les sulfates sous conditions anaérobiques. Les sulfures posent des problèmes en terme d'odeur et de corrosion au niveau des égouts ainsi que des stations d'épuration. Le problème est accentué dans le cas de températures élevées, de concentrations en DCO importantes, de long temps de rétention ainsi que de diamètre de conduite (ratio volume/section). Pour les conduites forcées récemment installées dans l'est de l'Autriche, il n'existe pas d'expérience pratique pour lutter contre la formation de sulfures. Dans le cadre de ce projet, des études pratiques basées sur diverses technologies ont été réalisées dans différentes conduites forcées. L'applicabilité et l'efficacité de la séparation mécanique du biofilm par «pigging», du control chimique avec addition de sels de fer et de nitrate ainsi que des systèmes d'aération ont été entre autres testés et évalués.

ABSTRACT

The transport of sewage in pressure sewers creates problems due to the production of sulphide by sulphate reducing bacteria under anaerobic conditions. Sulphide causes both corrosion and odour problems in sewage systems and treatment plants. The problem is favoured by increasing temperatures, high COD concentrations, retention time and pipe diameter (ratio volume/surface). For the recently built pressure sewers in the east of Austria no practical experience existed to combat sulphide production. Within this project, practical investigations with several technologies were carried out in different pressure sewers. Applicability and effectiveness of mechanical removal of biofilm by pigging, chemical control with addition of iron and nitrate salts and air supply systems amongst others was tested and evaluated.

KEYWORDS

Chemical addition, hydrogen sulphide production and control, pigging, pneumatic waste water transport, pressure sewer.

1   INTRODUCTION

Sewers are necessary to collect and dispose sewage to the waste water treatment plants. Long residence times of waste water in these facilities allow bacteria to use up oxygen and nitrate leading to anaerobic conditions. As a result of anaerobic processes organic acids and sulphide are produced. Attached bacteria growth at the pipe wall as biofilm is mainly responsible for these processes.

Dissolved sulphide is not only a possible cause for bulking sludge in WWTPs, but due to the pressure decrease may as well leak from the wastewater into the atmosphere at intermediate pumping chambers or at the discharge point of the pipe.

Apart from its annoying odour (odour threshold between 0,002 and 0,15 ppm), sulphide can be as toxic as cyanide at higher concentrations and has already caused many fatal accidents in sewer facilities (Wagner 1979). Sulphide production is also a main cause of corrosion problems, due to its biochemical oxidation to sulphuric acid under aerobic conditions. Corrosion processes related to hydrogen sulphide can lead to considerable damage, especially in concrete sewers (Lens and Pol, 2000).

Waste water composition, temperature and pipe dimensions are decisive factors for sulphide generation. These facts have been considered by different authors in the literature to develop prediction models to calculate sulphide generation in sewers (ATV 1992, Boon and Lister 1975, Hadjianghelou 1984, Nielsen et al. 1998, Pomeroy 1959). Some of these models are listed in Table 1.

Source	Considered Parameters	Model equation
ATV-A 116	Retention time, Diameter	$\Delta S = \dfrac{C \cdot t}{d}$
Hadjianghelou	Temperature, Retention time, Diameter	$\Delta S = \dfrac{0,975 \cdot t}{D} \qquad \Delta S = \dfrac{0,67 \cdot t^{1,07}}{D} \cdot 1,07^{(T-20)}$
Pomeroy	BSB$_5$, Temperature, Retention time, Diameter	$\dfrac{d[S]}{d[t]} = 1,0 \cdot 10^{-3} \cdot BSB_5 \cdot 1,07^{(T-20)} \cdot r^{-1} \cdot (1 + 0,37 \cdot D)$
Boon & Lister	CSB, Temperature, Retention time, Diameter	$\dfrac{d[S]}{d[t]} = 0,228 \cdot 10^{-3} \cdot CSB \cdot 1,07^{(T-20)} \cdot r^{-1} \cdot (1 + 0,37 \cdot D)$
Nielsen, Hvitved-Jacobsen, Raunkjaer	CSB, Temperature, Retention time, Diameter	$rs = a \cdot (COD_{sol} - 50)^{0,5} \cdot 1,03^{(T-20)}$

Table 1: Prediction models for sulphide generation in sewers

These models were applied to some of the pressure sewers involved in this project (Figure 1). For the big diameter sewers (Nord and West collectors in AWV NSW and HPW in Guntramsdorf) all sulphide predictions and the measured sulphide concentrations are more or less in the same magnitude. However, for the smallest diameter pipes Pannonia, BP Raststätte and Übersbach models predict even three times higher sulphide concentrations in comparison to the measured ones. Especially the prediction models from Pomeroy and ATV overestimate sulphide generation while Boon and Lister and Hadjianghelou often get similar predictions, which are also closer to the real values. Moreover, none of these prediction models take into account many pressure sewers connected in series with intermediate pumping stations, which was the case in many of the sewer systems considered. There is an enhancement of sulphide generation in the following pressure pipes if the incoming sewage is already septic.
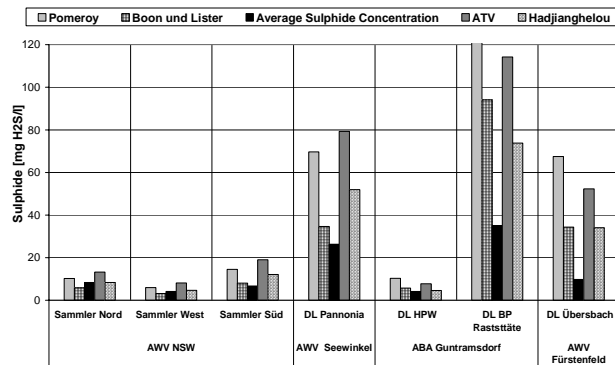
Figure 1: Average sulphide concentrations and prediction values for the investigated sewers

2   AVAILABLE TECHNOLOGIES FOR SULPHIDE CONTROL

There are two main strategies to attempt the control of sulphide in sewers: preventing sulphide formation removing the biofilm from the pipewall or avoiding anaerobic conditions in the sewer or eliminating the existing sulphide both in the liquid and in the gas phase.

Since most of the sulphide production takes place in the biofilm attached to the surface of pipes and sewers the removal of this biofilm is certainly a method to avoid sulphide generation. Pigging is the most frequently applied method to remove attached biofilms. However in bends and siphons plugging can cause severe problems.

Activity of anaerobic microorganisms like sulphate reducing bacteria is also inhibited by an increase in the Redox potential which can be achieved with the addition of nitrate salts (Barjenbruch, 2001) causing anoxic conditions in the sewer or by air or oxygen supply to avoid septicity (Boon and Lister 1975, USEPA 1985).

The biofilm can also be damaged by adding chemicals which directly attack the organisms in the biofilm. This is possible by the application of lime which leads to an increase of pH above 11 inhibiting bacterial activity in the biofilm.

Another possibility is the elimination of produced sulphide with addition of iron salts. Iron reacts with sulphide to iron sulphide as follows: $H_2S + Fe^{2+} \rightarrow FeS + 2H^+$. Because of the very low solubility product of iron sulphide ($K_L = 5*10^{-18}$ mol^2/l^2) precipitation occurs. Stoichiometry shows that 1 mol Fe^{2+} is needed to precipitate 1 mol S^{2-}. Precipitation with Fe^{3+} salts is also possible because as a result of the low redox potential in the sewage Fe^{3+} is rapidly reduced to Fe^{2+}.

3   PRACTICAL INVESTIGATIONS

3.1   Monitoring

During the last three years experiments were carried out in existing pressure sewers (Matsché et al, 2005). Several methods were tested under different conditions in different locations. It was the aim of the investigations to find optimal solutions both in respect to operating conditions and economical efficiency.

A prototype monitoring station for observation of hydrogen sulphide production related processes was installed at the discharge point of the pressurized sewer pipes (Saracevic et al., 2005). Different probe systems were applied, such as a

multi-electrode in-situ probe for ion sensitive electrodes (S^{2-} and NO_3^-) and electrodes for pH and redox. Reference sulphide measurements were carried out using the methylen-blue method (DIN 38405-D26).

3.2   Removal or elimination of H_2S producing microorganisms

The formation of H_2S is mainly taking place in the biofilms that are attached to surfaces like sewer wall or pipes. Our first approach was therefore to reduce H_2S production by the removal of the biofilms. This was done mechanically by a conventional pigging with "pigs" that were forced through the pressure pipe erasing the biofilm. This technique could also be used to estimate the thickness of the biofilm by harvesting the removed biomass at the end of the treated pressure sewer.

An alternative to the conventional pigging was developed and applied very successfully on different sewer pipes using Leca granules (Light expanded clay aggregate) which are transferred into the pipe by means of a pressure vessel. When the waste water pumps are activated, the Leca granules behave like a mobile piston through the pipe erasing the biofilm. This technique has the advantage of flexibility (no danger of plugging in siphons and bends) and significantly lower costs as compared to the conventional pigging.

Despite the good removal of biofilm, the formation of H_2S resumed after 3 to 4 days, which limits the applicability of this method for controlling sulphide generation.

Another method comprises the destruction of the microorganisms in the biofilm by means of a shock-exposure to lime, increasing the ph up to 13. However the effect of this method was also not sustainable and, similar to the mechanical removal, the lime treatment inhibited the H_2S formation for 3 to 4 days only.

3.3   Prevention of H_2S production with chemical addition

The addition of nitrate compounds into pressure sewers creates anoxic conditions, increasing the redox potential and inhibiting sulphate reduction and thus sulphide generation (Barjenbruch, 2001). Additionally denitrification creates alkalinity resulting in a light increase in ph, and therefore in a reduced tendency for H_2S leakage into the atmosphere. Experiments with $Ca(NO_3)_2$ were carried out in the Neusiedler See region. In this area three pressure sewers (Table 2) are connected to a central waste water treatment plant (Figure 2).
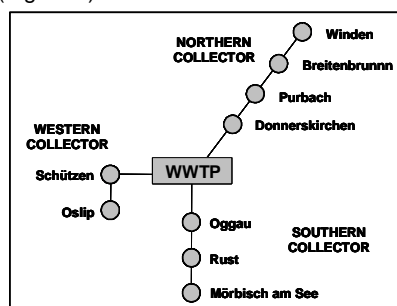

Figure 2: Scheme of the sewer system in Neusiedler See region

A commercial product containing $Ca(NO_3)_2$ was added at the pumping station nearest to the WWTP of each sewer. The dosage was determined depending on the sewage strength and temperature. As additional control, sulphide concentrations in the atmosphere and in sewage at the discharge point of the pipe at the WWTP were used for adjustments (Saracevic et al, 2005b). Typical results of operation are shown in Figure 3.

Collector portion	Length	Diameter	Sewer section	Sewer volume	Average sewage flow	Pump power	Ret. time
	m	mm	m²	m³	m³/d	m³/h	h
PS Donnerskirchen (North)	4560	443	0,154	702,85	3443,1	450	4,9
PS Schützen (West)	1346	248	0,048	65,02	921,6	150	1,7
PS Oggau (South)	5034	399	0,125	629,43	2391,4	400	6,3

Table 2: Characteristics of the pressure sewers in the Neusiedler See region
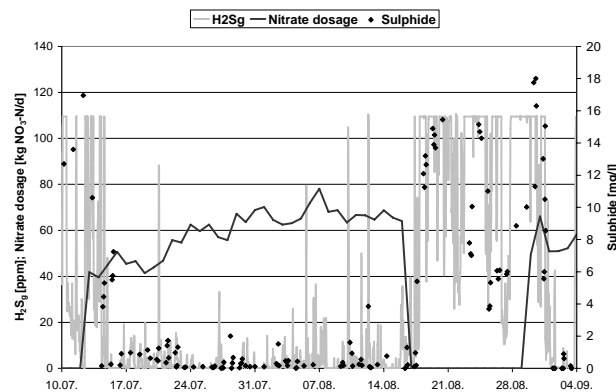

Figure 3: Nitrate dosage in pump station Donnerskirchen (northern collector)

The obtained data indicate that sulphide both in the atmosphere and in sewage decrease significantly only 3-4 days after commencement of the nitrate addition. The dosage varied according to the demand as mentioned previously. The setting of the dosing quantity was rather short, what resulted in occasional appearance of low sulphide concentrations at the measuring point. An interruption of the dosage resulted in a resuming of high sulphide concentrations within 2 days.

The application of nitrate for sulphide control not only reduces sulphide production but also leads to anoxic decomposition of organic compounds, which results in a higher demand of nitrate (over stoichiometrically calculated) and an increase of biofilm thickness. The decomposition of organic compounds applies mainly for the easily degradable fraction and can result in a reduced denitrification capacity at the WWTP.

3.4 Chemical elimination of sulphide

Elimination of the generated sulphide can be achieved with chemical addition. Technologies based on this principle attempt to precipitate or adsorb sulphide removing it from the sewage.

Investigations were made with zeolite, a silicate mineral with a high specific surface commonly used as a molecular sieve and gas purifier. However, adsorption of sulphide from sewage did not take place as expected. Only slightly lower concentrations of sulphide were measured when zeolite was added. An explanation for these negative results may be the saturation of the zeolite with other substances rather than sulphide, due to the high sewage concentrations and the low specificity of zeolite.

Special products to control sulphide by precipitation containing Fe (II) and Fe (III) salts were successfully applied in a pressure sewer of 4105 m length and 200 mm diameter with an average waste water flow of 355 m³/d in Styria. The results are shown in Figure 4.
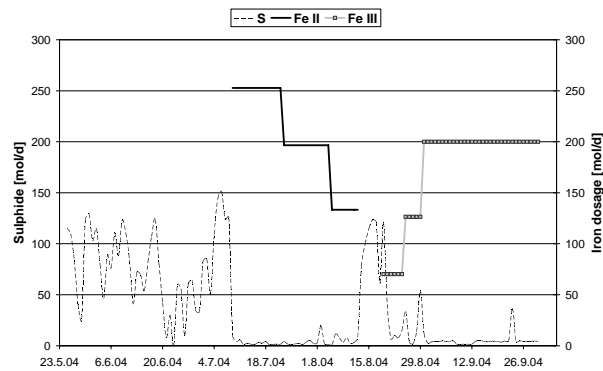
Figure 4: Fe (II) and Fe (III) dosage in Fürstenfeld (Styria)

Due to the nearly instant reaction of precipitation, sulphide is removed immediately after addition of precipitant. On the other hand, sulphide concentration rises again shortly after an interruption of dosage or insufficient precipitant supply, which means that iron only removes generated sulphide but does not inhibit sulphide generation.

With a dosage of 253 and 197 mol Fe/d sulphide concentration in water was reduced to values below 1 mg/l. However with a dosage below 133 mol Fe/d, H_2S concentration in water increased to 4 mg/l indicating insufficient iron for a complete sulphide removal. The optimal dosage was estimated with 175.5 mol Fe /d (50 l/d) for both products.

At the waste water treatment plant another product containing iron chloride was used for phosphorous precipitation. The efficiency of this product to precipitate sulphide in this sewer was also tested and brought the same satisfying results at a lower price than the specific products.
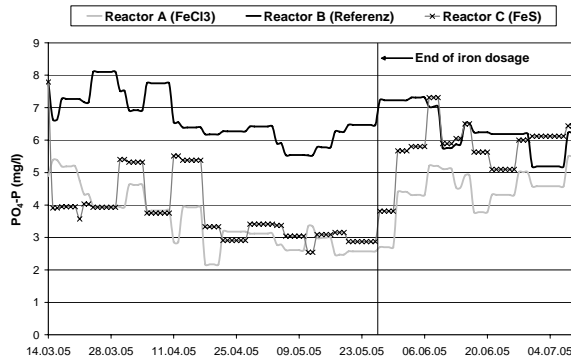

Figure 5: Iron potential to precipitate both sulphide in sewers and phosphorous at the WWTP

For this sewer the daily dosage of iron to treat sulphide was more than one third of the daily iron dosage for phosphorous precipitation at the WWTP. The precipitated FeS may be oxidized to $FeSO_4$ in the aeration tank and could consequently serve as precipitant for phosphorous, which could mean a significant reduction in costs for phosphorous removal. This could not be observed at the WWTP. However, investigations in the laboratory have shown that this effect takes place (Figure 5).

A combination of precipitation with iron and anoxic conditions can be obtained when $Fe(NO_3)_3$ is applied for sulphide control. This chemical was tested in a sewage pipe of 3220 m length, 150 mm diameter and 147 m^3/d waste water flow in Burgenland (AWV Seewinkel). In this case dosage was determined considering flow and strength of the waste water and pipe length and diameter. Additional adjustments were performed according to analytical measurements of H_2S in sewage at the end of the pipe. Similar results to the nitrate experiments were obtained, except for the lag at the beginning of the dosage, which was significantly shorter with iron nitrate.

3.5 Prevention of sulphide production with pneumatic transport and air supply systems

Production of hydrogen sulphide can also be avoided in case anaerobe conditions are inhibited by the injection of compressed air. Two systems were successfully tested (Matsché et al, 2005): System Hölscher (pneumatic waste water transport) and System Bühler (compressed air supply).

At the Hölscher system waste water flows by gravity into a collecting tank to a certain level. At this stage the influent valve is closed and the effluent valve to the pressure pipe opens. Compressed air is introduced at the top of the collecting tank which is emptied pneumatically into the pressure sewer. The high velocity of the water in the sewer together with the air avoid the formation of anaerobic biofilms and therefore the generation of hydrogen sulphide. No pumps are used for water transport in this setup.

The second system combines a conventional pumping of the waste water with an intermittent supply of compressed air directly into the pressure sewer. This compressed air expands in the pipe accelerating the water column discontinuously. This discontinuous movement of the water column has a similar effect like pigging in terms of biofilm removal.

4 CONCLUSIONS

The aim of the investigations to find out the most effective methods to control sulphide problems in pressure sewers resulted in the following conclusions. There are many effective methods to control sulphide production but some methods may be more suitable and efficient than others, depending on the characteristics of the pressure sewer. Chemical addition of nitrate and iron salts was successfully tested and can be recommended for existing pipes due to its easy adaptability. However local conditions for a pre-evaluation of the sulphide potential (Boon and Lister, 1975), possible chemical consumption and price must be taken into account in the selection of the chemical. The treatment costs for the different methods with addition of chemicals for the control of H_2S can either be based on the amount of wastewater treated or on the load of potential H_2S production (Figure 6).

More significant information about the expected treatment costs is certainly obtained on the basis of eliminated hydrogen sulphide since an efficient treatment depends on the removed load of hydrogen sulphide. Sewage of similar quality can produce significantly different amounts of sulphide depending on retention time and diameter of the pipe and sewage temperature and COD concentration. The treatment costs at the AWV Seewinkel and RHV-NSW Western collector can serve as an example. In the case of AWV Seewinkel Pannonia concentrated sewage from a holiday resort with separate sewer system was pumped to the WWTP in a relatively small pipe (diameter 150 mm) which resulted in very high sulphide concentrations (up to 40 mg/l). Therefore the costs for treatment based on cubic meter were extremely high as compared to the western collector (RHV NSW) (ratio 1:9). Costs based on eliminated sulphide are still the highest, however the ratio is reduced to 1:1,5.
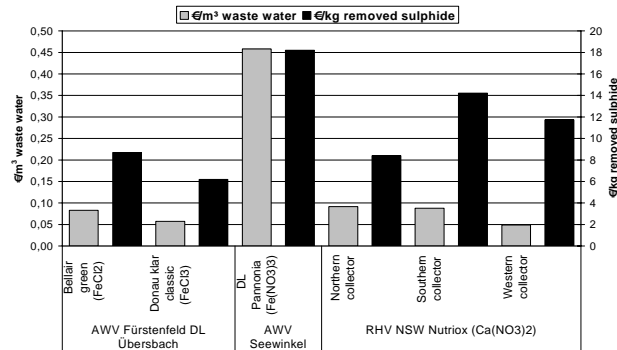
Figure 6: Costs for chemical addition

The traditional "pigging" was shown to have a very short lasting effect in comparison with its high price and therefore application is limited to few cases. On the contrary, a "pigging" with Leca combined with chemical addition was observed to reduce the consumption of chemicals for approximately a week.

Air supply systems can be used as an alternative to addition of chemicals in existing pipes. This method is especially advantageous in case of very high sulphide generation potential in small diameter pipes and concentrated sewage. Operation mode can easily be adapted to the prevailing conditions with lower or higher air demand (day/night or dry weather/storm water or summer/winter). Operation costs depend on the amount of air supplied and the energy consumption of the compressor.

Pneumatic waste water transport is a good alternative for new pipes. It is a sewage transport system itself and can not be retrofitted in existing pipes. The decision for the installation of this system has to be made before the construction of the sewer system.

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