IMPACT OF CHEMICAL DOSING OF SEWERS ON WWTP PERFORMANCE

An integrated model assessed the interaction of sulfide control in sewers with N and P removal at the wastewater treatment plant.

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Abstract
This paper reports an integrated modelling methodology for simultaneously investigating the effects of network dosing of chemicals on sulfide control in sewers and N and P removal at the downstream WWTP. The changes in influent due to chemical dosing are considered in evaluating the WWTP performance. For the sewer system studied here, oxygen is the most cost-effective option without considering the impact on the WWTP. Once the impact on the WWTP is included, the operational cost for oxygen increases, as an extra carbon source is needed to improve the N removal performance. Ferric chloride becomes the most cost-effective option since it also enhances P removal.

Introduction
Hydrogen sulfide, which is produced by sewer biofilms as a result of sulfate reduction under anaerobic conditions, has long been identified as a major cause of corrosion and odor problems in a sewer system. Dosing of various types of chemicals to wastewater is widely used by the water industry as a control measure for these problems. Oxygen/air, nitrate salts, iron salts and magnesium hydroxide are the commonly used chemicals. Although these chemicals are effective in controlling sulfide in sewers, their dosing also changes the composition of wastewater entering the downstream wastewater treatment plant (WWTP). This is expected to have significant impacts on the WWTP performance, as outlined in Table 1.

However, to the best knowledge of the authors, no methodology or tools have been reported in literature to enable a quantitative assessment of the impact of chemical dosing in sewer networks on the performance of the downstream WWTP. The optimisation of dosage is generally based on the effectiveness of sulfide control alone and the associated operational costs (de Haas et al. 2008). This approach likely yields sub-optimal solutions.

In this paper, we report an integrated modelling methodology for simultaneously investigating the effects of network dosing of chemicals on sulfide control in sewers and N and P removal performance at the downstream WWTP.

Integrated Modelling of a Sewer System and WWTP
The Elanora WWTP of Allconnex Water, along with the Tugun-Elanora sewer network that feeds this plant, is used as a case study. The Tugun-Elanora sewer system, which consists of rising main pipes 100–600mm in diameter with a combined length of 13.9km, collects domestic sewage from 13 pump stations with an average total daily flow of 15ML. The WWTP was designed for biological carbon and nitrogen removal. Phosphorus removal is achieved through ferric chloride dosing at the treatment plant.

The work was accomplished by integrated modelling of the biotransformation processes in both sewer systems and wastewater treatment plants. The SeweX Model previously developed at the University of Queensland and calibrated for the Tugun-Elanora sewer system (Sharma et al. 2008a, 2008b) was used to simulate the effects of four chemicals, namely oxygen, nitrate, magnesium hydroxide and ferric chloride, on sulfide control in sewers. The model describes biological, chemical and physical processes that occur in the sewer system, and can be used to investigate temporal and spatial variations of sulfide production in rising or gravity main sewers. Furthermore, the model is capable of predicting changes in wastewater composition, including pH with chemical dosing. Several simulations were carried out to identify optimised dosing of chemicals considering both the location and the rate of dosing, in order to achieve a pre-set level of dissolved H2S.

### Table 1: Effects of chemical dosing on sewer and WWTP performance

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Effects to sewer</th>
<th>Changes in wastewater composition</th>
<th>Expected impact on WWTP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen and nitrate</td>
<td>Preventing anaerobic conditions, oxidises sulfide already present</td>
<td>Reduction in organic matter (COD)</td>
<td>Deteriorated nutrient removal performance due to reduced carbon supply</td>
</tr>
<tr>
<td>Ferric/ferrous chloride</td>
<td>Precipitating sulfide in sewer forming insoluble precipitate (FeS)</td>
<td>Some COD reduction due to precipitation of colloidal organic matter is possible, presence of FeS</td>
<td>Oxidation of FeS under aerobic conditions releases Fe²⁺, which can be used for phosphate precipitation (Gutierrez et al. 2010)</td>
</tr>
<tr>
<td>Magnesium hydroxide</td>
<td>Elevating pH in sewer, shifts sulfide equilibrium to HS⁻ and prevents H₂S release</td>
<td>Increase in alkalinity</td>
<td>Possible improvement of nitrification in case that wastewater has low alkalinity</td>
</tr>
</tbody>
</table>
at the WWTP inlet (Figure 1). The results show that the proposed dosing of oxygen, nitrate and ferric chloride was effective in controlling the dissolved sulfide levels to an average of 1mg S/L. With the dosing of magnesium hydroxide, the average hydrogen ion concentration at the WWTP inlet could be raised $3.3 \times 10^{-9}$, which gives a pH of 8.5.

As discussed earlier, some changes in the wastewater composition critical to N and P removal in WWTP were observed (Figure 2). Oxygen and nitrate both oxidise the hydrogen sulfide produced in sewer biofilm. Sulfide is oxidised both chemically and biologically with oxygen, while nitrate can only oxidise it biologically. The rate of sulfide oxidation with nitrate is thus lower than that with oxygen, especially in large pipes where chemical oxidation plays a major role. Consequently, nitrate requires a longer contact time for complete sulfide oxidation as compared to oxygen. In addition to the oxidation, both oxygen and nitrate promote heterotrophic activity in biofilm, thereby oxidising a significant amount of organic matter in sewage. The addition of both oxygen and nitrate thus resulted in reduced levels of volatile fatty acids (VFA) in the feed (Figure 2B). The impact was much more pronounced in the case of nitrate than in the case of oxygen. Simulation results revealed that, compared to oxygen, a much larger amount of nitrate (in terms of electron-accepting capacity) was required to achieve the same level of sulfide control, resulting in more consumption of organic carbon through denitrification. This was because of the longer contact time needed for sulfide oxidation as described above. It is worth mentioning here that the amount of VFA consumed would vary depending upon the amount of oxidant used and the location of its dosing.

Dosing of ferric salts resulted in hydrogen sulfide precipitation in the form of FeS precipitates (Figure 2C), which would enter the WWTP. Laboratory studies reported in Gutierrez et al. (2010) have shown that a negligible fraction of FeS particles will be retained in the primary settling tank in this case, as the FeCl₃ was dosed close to the WWTP inlet, resulting in a short contact time insufficient for FeS colloids to form large-sized particles. Once the FeS particles enter the WWTP, FeS precipitates get oxidised to Fe⁺³ and SO₄⁻² in the aeration tank and the Fe⁺³ thus formed results in the precipitation of PO₄⁻³ (Gutierrez et al., 2010). The dosing of magnesium hydroxide caused elevated pH levels (Figure 2D).

The IWA Activated Sludge Model No. 2d (ASM2d) (Henze et al. 2000) was

![Figure 1: Dissolved sulfide levels with the dosing of different chemicals.](image1)

![Figure 2: Changes in wastewater composition due to chemical dosing in sewer](image2)

(A) Comparison of dissolved H₂S levels with various chemical dosing
(B) Effects of oxygen/nitrate dosing on VFA
(C) Ferric chloride dosing producing FeS
(D) Mg(OH)₂ dosing elevating pH

Baseline data are those predicted by the SeweX model without any chemical dosage.
employed to assess the performance of the WWTP. Additional components were added to the ASM2d model to take into account the processes of FeS oxidation occurring in aerobic reactors, which leads to Fe$^{3+}$ regeneration and phosphate precipitation (Gutierrez et al., 2010). The default model parameter values recommended in Henze et al. (2000) for the ASM2d model and parameters determined through experiments for the additional processes were used for the simulation studies. The SeweX and ASM2d models use very similar state variables, characterising the composition of wastewater so that the interface between the two models was conveniently developed.

Results and Discussion

Figure 3 shows the impacts of chemical dosing on the WWTP performance as obtained by WWTP model simulations. The consumption of organic carbon due to nitrate or oxygen addition (Figure 2B) resulted in deterioration of N removal by the WWTP (Figure 3A), which required addition of a readily available carbon source (for example, methanol) to improve the N removal performance to the same level as in the case without dosage.

FeS precipitates formed as a result of Fe$^{3+}$ dosing in the sewer were found to enhance the phosphorus removal in the WWTP (Figure 3B). The amount of ferric added to the sewer to achieve satisfactory sulfide control was found to be sufficient to achieve an effluent phosphate level of approximately 2.5 mg P/L, which is comparable to that achieved through deliberate addition of ferric chloride to the WWTP for the purpose of chemical P removal (Figure 3B). It is worthwhile to note that the amount of ferric chloride added to the sewer network to achieve simultaneous sulfide and P control was approximately the same as that which is currently added to the treatment plant. The use of a chemical for multiple purposes clearly demonstrates the value of integrated sewer and WWTP management.

The impacts of elevated pH on biological activities in the WWTP were not considered. It is assumed that the pH level of around 8.5 will not have any significant impacts on biological N removal. The addition of Mg(OH)$_2$ and the resulting higher pH can result in the formation of struvite (MgNH$_4$PO$_4$.6H$_2$O), which may cause problems due to its precipitation in pipes. The precipitation of struvite is controlled by a combination of factors, such as thermodynamics of liquid-solid equilibrium, phenomena of mass transfer between solid and liquid phases, kinetics of reactions, and several physiochemical parameters; hence, the prediction of struvite precipitation is complex (Corre et al. 2005).

For simplicity, the precipitation of struvite can be considered to occur when the product of activities of magnesium, ammonium and phosphate ions exceeds the thermodynamic solubility product (Ksp) of struvite (Bhuiyan et al. 2008). With typical levels of ammonia (~50 mg N/L) and phosphate (~7 mg P/L) in domestic wastewater, struvite precipitation is likely to occur at pH above 9 when magnesium hydroxide is dosed in excess. However, the amount of struvite is not expected to be significant as small changes in concentration of NH$_4^+$ and PO$_4^{3-}$ will result in the product of activities being less than the solubility product.

Based on the simulation results discussed above, a comparison of operational costs for all the four options of chemical dosing was carried out as shown in Table 2. The cost estimate was based on the amount of chemicals needed to achieve a desirable sulfide level in the sewer (below 1 mg S/L) and the impact on WWTP performance. The operating costs for oxygen and nitrate included the cost of chemicals (carbon source) required to improve the N removal to a level similar to the

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Sewer</th>
<th>N Removal in WWTP</th>
<th>P Removal in WWTP</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>$161,700</td>
<td>$155,200</td>
<td>$284,800*</td>
<td>$601,700</td>
</tr>
<tr>
<td>Calcium nitrate</td>
<td>$492,300</td>
<td>$328,100</td>
<td>$284,800</td>
<td>$1,105,200</td>
</tr>
<tr>
<td>Ferric chloride</td>
<td>$298,000</td>
<td>$0</td>
<td>$0</td>
<td>$298,000</td>
</tr>
<tr>
<td>Magnesium hydroxide</td>
<td>$418,800</td>
<td>$0</td>
<td>$284,800*</td>
<td>$703,600</td>
</tr>
</tbody>
</table>

*Based upon the cost of Fe$^{3+}$ currently being used @ 9.5 mg/L and other maintenance costs.
one without any chemical dosing. The cost of P removal in the WWTP includes the cost of FeCl₃ currently being dosed and associated maintenance costs. Without considering the impact on WWTP, oxygen is the most cost effective option. Once the impact on WWTP is included, the operational cost for oxygen increases, as an extra carbon source is needed to improve the N removal performance. Thus ferric chloride becomes the most cost-effective option, as Fe⁢⁺⁺ can be re-used to precipitate phosphate without the need of ferric dosing in the treatment plant.

Conclusions

This paper presents a methodology of investigating the impacts of chemical dosing in sewer networks on N and P removal in WWTP. Current practice of selecting the chemical dosing based on the effectiveness on sulfide control doesn’t yield optimal solutions, as the impacts on the performance of WWTP are completely ignored.

This study demonstrates the need for integrated modelling of sewer systems and wastewater treatment plants for the assessment of the options of chemical dosing in sewers. Sewer and WWTP models have been illustrated as valuable tools for optimal sewer management.

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References:


