Understanding the Effects of Changes in Sewer Wastewater Quality on Wastewater Treatment Plant Processes

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Abstract

The increasing concentration of sulphides within sewer wastewater poses challenges for asset and safety health management at water utilities. While chemical dosing is a common control method, it can alter the wastewater composition, affecting treatment plant performance. This paper aims to gain a better understanding of the impacts of chemical dosing strategies within the sewer on treatment plant processes. The study integrates the SeweX model and peer-reviewed literature to investigate the changes in composition of sewer wastewater after chemical dosing strategies, while expert opinions are utilized to assess their impact on treatment plant processes. Results showed that $Mg(OH)_2$ dosing upstream controls sulphides, increases alkalinity, and conserves organic sources. While it offers limited benefits for nitrogen removal in systems with sufficient alkalinity and carbon, it significantly improves ammonium oxidation and NOx reduction in systems with limited resources, without harming aerobic sludge digesters. In-sewer dosing of $FeCl_3$ can effectively decrease sulphide concentrations in sewers and form FeS precipitates. These changes improve phosphorus removal in treatment plant processes, reduce dissolved sulphide concentrations in anaerobic sludge digesters, and enhance the settleability and dewaterability of activated sludge in the downstream treatment plant. Lastly, in-sewer oxygen injection reduces sulphides and volatile fatty acids in the sewer, leading to reduced nitrogen removal in the downstream treatment plant.

1. Introduction

In-sewer dosing of chemicals has been recognised as one of the main solutions for controlling the formation of sulphides in sewer networks (Ganigue et al., 2011). Chemical dosing strategies are commonly used such as magnesium hydroxide, ferric chloride, and oxygen (Ganigue et al., 2011). Evaluating the effectiveness and cost efficiency of chemical dosing options typically focusses on their ability to regulate sulphide levels at the end of the sewer system. The potential impacts of changes in wastewater composition resulting from chemical dosing on the performance of wastewater treatment plants are often overlooked when designing measures to control sulphide in sewers. In particular, some of the chemicals would bring advantage, while the others would negatively affect on downstream treatment plant processes (Sharma et al., 2012). A careful consideration of these effects is needed to make optimal selection from the available options for sulphide control and prevent detrimental effects on treatment plant efficiency.

A realistic comparison is needed to validate the potential impacts on treatment plant processes based on empirical insights from operators. This study was carried out to investigate the overall performance of network dosing chemicals in both the control of sulphide at the targeted location and treatment plant processes in terms of nitrogen removal, phosphorus removal, and sludge settleability. A wastewater system and experimental trial in Southern area (Western Australia) was used as the case study.

1.1 Current methods for investigating the impact of chemical dosing

1.1.1 Integrated modeling of chemical dosing impacts in sewers

The dynamic nature of sewer systems makes constant chemical dosing inefficient, often resulting in overdosing or underdosing, which increases costs (Liang et al., 2019). Demand-driven dosing strategies, which rely on accurate predictions of sulphide production, are more effective (Cen et al., 2023). The SeweX model is crucial in this context, as it predicts sulphide formation and guides chemical dosing by simplifying biofilm reactions into basic kinetics (Sharma et al., 2013). Moreover, SeweX can generate training data for machine learning algorithms, potentially enhancing future sulphide control systems with better predictions and optimized dosing. An integrated modeling approach using SeweX for sewers and ASM2D for wastewater treatment plants (WWTPs) has been developed to assess the effects of chemical dosing on nutrient (N and P) removal (Sharma et al., 2012). This study emphasizes the critical role of integrated modeling in optimizing sewer management and evaluates the effects of $Mg(OH)_2$, $FeCl_3$, and oxygen.

1.1.2 Laboratory – full scale wastewater systems

Full-scale laboratory studies have greatly improved the understanding of chemical dosing in sewers and its impact on downstream wastewater treatment. $Mg(OH)_2$ dosing increases sewage pH, reduces sulphide and methane levels, and enhances nitrogen removal, while making sludge management easier (Cen et al., 2023). Similarly, iron ($FeCl_3$) dosing effectively reduces sulphide levels, lowers phosphate in treated water, and cuts hydrogen sulphide in biogas (Rebosura, 2018). These studies emphasize the value of full-scale experiments in optimizing dosing strategies without harming wastewater treatment processes.

1.2 Project objectives

This project investigates the effects of chemical dosing strategies, including magnesium hydroxide ($Mg(OH)_2$, ferric chloride ($FeCl_3$), and oxygen on controlling sulphides in sewer networks. Combining SeweX modeling, laboratory-scale studies, and expert opinion, the focus is on the Southern wastewater catchment to simulate wastewater quality and assess the impact of these strategies on downstream treatment processes. This comprehensive approach will help guide selection of effective dosing methods and suggest further experimental trials to refine these strategies for optimal wastewater management.

2. Process

The project focusses on an example wastewater system, where there is significant concern regarding odour and hazardous gases. Although SeweX has been used in Water Corporation to assess hotspots, when concerning chemical dosing in sewer, the model does not consider the deposition of solids and precipitates in sewer system. This omission might affect the prediction of Sulphide levels (Sharma et al., 2012). The project objective has been achieved through two main tasks: predicting potential changes of wastewater composition in sewers, and assessing the impacts on treatment plant processes, with four stages as illustrated in figure 1:

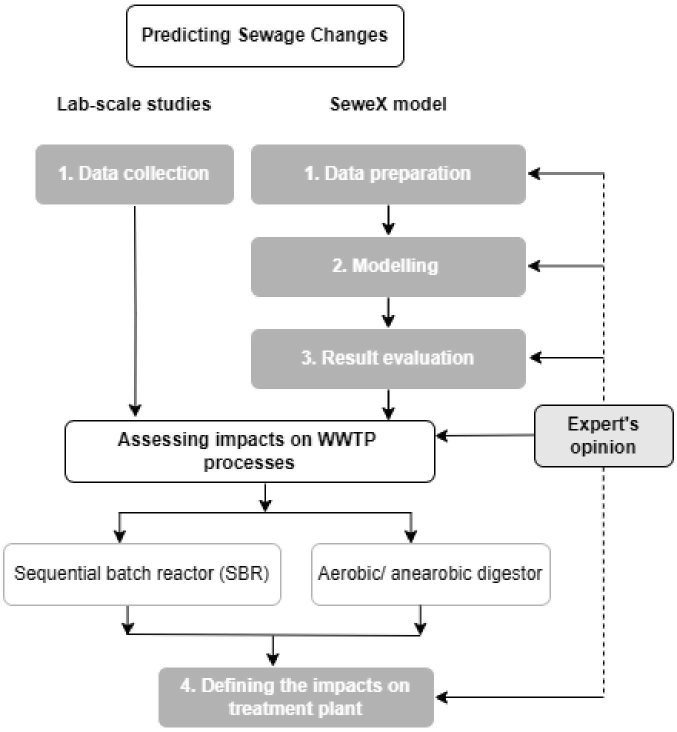

Figure 1 Diagram of project process

During the first and second stage, $Mg(OH)_2$ dosing was simulated to predict changes in the wastewater composition of the Southern sewer network. The input data for the SeweX model was developed using real data provided by the Water Corporation. In-sewer dosing of $Mg(OH)_2$ during the experimental trial was utilized to measure components and guide simulations. Alongside the SeweX simulation, literature was reviewed to investigate the change in sewer wastewater quality in-sewer dosing of $Mg(OH)_2$, $FeCl_3$, and oxygen. For the third stage, result validation was conducted against the example area experimental trial to identify any potential biases using linear regression, percentage deviation, and standard deviation. The final stage involved defining the impacts on treatment plant processes, which was done by consulting experts at the Water Corporation who have extensive experience working on treatment plant and were involved in the example area trial to qualitatively assess the actual impacts on the treatment plant.

	Input parameter	Value
Input parameters	Local lab sample	Laboratory monitoring before chemical dosing concentration
	Temperature	25°C
	Pipe material	Plastic lined
Changed parameter	$Mg(OH)_2$ concentration	40 dose rates

Table 1 SeweX fixed parameters and adjustable parameters in the simulation

3. Results and Discussion

3.1 The changes of wastewater composition in sewer

3.1.1 Wastewater compositions predicted by SeweX model

Simulating the dosing of $Mg(OH)_2$ in SeweX model elevated pH levels (from 7.5 up to 8.5). The overall production of sulphide was lower due to the elevated pH conditions inhibiting the release of the hydrogen sulphide gas responsible for the odour problem. The linear regression showed a strong negative correlation between pH and H_2S. In other words, when the pH increses, H_2S concentration decreases significantly in experimental data. The results of percentage deviation showed that the experimental data demonstrates greater variability up to ± 60%, while the simulation data offers a more controlled and stable correlation with under 10% variance, highlighting the differences between real-world complexity and modeled predictions.

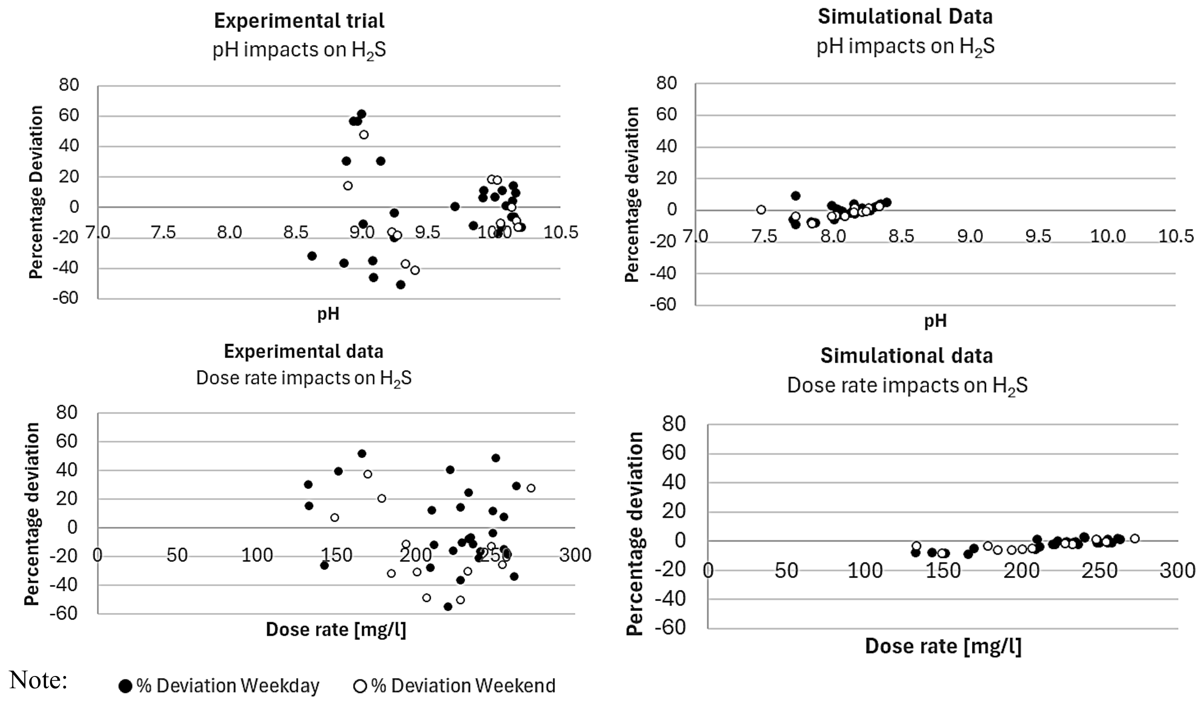

Figure 2 Comparision of experimental data and simulation data during weekdays and weekends across different phases of the experimental trial

The simulation data is more consistent, with lower standard deviations (3.9 for pH and 3.2 for dose rate) compared to the experimental data (27.5 and 28.4). The SeweX model was good at predicting the trend but the specific values are different from the experimental pH and H_2S concentrations. The results predicted from the SeweX model can not be used directly to assess the impact on treatment plant processes. This indicates that real-world conditions are more variable, underscoring the need for more observations, samples and trials to calibrate the model.

3.1.2 Wastewater compositions predicted by literature

In-sewer dosing of $Mg(OH)_2$, a weak base known for its safety in handling and storage, can raise pH to a maximum of around 9.0 due to its limited solubility (0.009 g/L at 18°C) (Zhang, 2023). In a laboratory study, adding 56 mg/L of $Mg(OH)_2$ to the sewer increased alkalinity, reduced H_2S by 35.1%, and decreased methane by 58.0%. However, high pH partially inhibited anaerobic processes, leading to increased COD (chemical oxygen demand) and VFA (volatile fatty acid) levels, with total COD in effluents rising by 9.0% compared to controls (Cen et al., 2023). From experts' opinion, wastewater in reality is well buffered, so elevating pH >9 would require a large dose rate. $FeCl_3$ dosing altered wastewater composition by oxidizing sulphide to elemental sulfur, reducing dissolved sulphide concentrations by 47.9% while affecting residual iron, phosphate, and COD levels (Zhang et al., 2023). Although total COD, methane, and pH remained stable, a slight increase in sulfate reduction was observed, challenging previous assumptions about iron salts inhibiting this process (Rebosura et al., 2018). Lastly, oxygen injection with levels (15-25 mgO_2/L) reduced daily sulphide production by 65%, increased oxygen uptake in the biofilm, and also reduced VFA levels (Sharma et al., 2012).

3.2 Potential impacts on treatment plant processes

Wastewater treatment plant was designed to treat domestic and commercal wastewater with capacity of 15ML/day. The treatment plant is design for biological carbon, nitrogen and phosphate removal, using a sequential batch reactor (SBR) and aerobic digestors process.

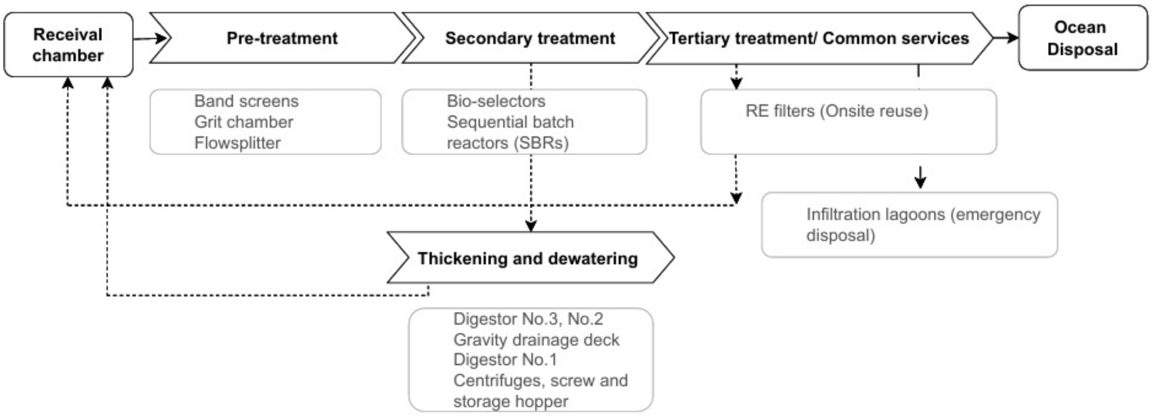

Figure 3 The wastewater treatment plant processes

Sewer chemical dosing had no discernible or measurable impact on SBR performance at experimental trial. Because the self-buffering nature of $Mg(OH)_2$ helps maintain an optimal pH balance without causing complications from overly high alkalinity levels. It has been demonstrated that $Mg(OH)_2$ dosing does not have detrimental effects on downstream nitrogen removal systems with sufficient alkalinity and carbon sources. In cases where the biological nitrogen removal process has limited alkalinity and carbon sources, changes in wastewater composition can improve ammonium oxidation and NO_x reduction, but it may also cause struvite precipitaiton in sludge sline (Cen et al., 2023). Laboratory studies on in-sewer dosing of $FeCl_3$ showed there is no adverse effects on treatment plant processes. On the contrary, these changes may improve phosphorus removal in secondary treatment due to the precipitation of PO_4^{3-} as FeS enters the secondary treatment (Rebosura et al., 2018). Lastly, oxygen injection can cause a deficiency in volatile fatty acids, which are crucial for nitrogen and phosphorus removal in SBR performance (Sharma et al., 2012).

The addition of $Mg(OH)_2$ into the sewer did not impact the performance of aerobic digesters at experimental trial, as observed by the operator. A result was observed with anaerobic digesters, where digested sludge dewaterability was enhanced in laboratory studies with both $Mg(OH)_2$ and $FeCl_3$ dosing (Cen et al., 2023; Rebosura et al., 2018).

4. Conclusions and Future Work

The SeweX model is effective for predicting sulphide control but there are many reasons for the different values between simulation data and experimental data. Future work is recommended to understand the causes for the discrepancy in results between the SeweX model and experimental data. In terms of controlling sulphides in sewers, $Mg(OH)_2$, $FeCl_3$, and oxygen are effective chemicals. Peer-reviewed studies and experts' opinion suggest that dosing with $Mg(OH)_2$ and $FeCl_3$ do not cause negatively impact on Sequencing Batch Reactors (SBRs) and aerobic/anaerobic digesters. Oxygen dosing, on the other hand, may interfere with nitrogen and phosphorus removal processes in downstream treatment plants. It is noted that $Mg(OH)_2$ dosing may lead to struvite precipitation in WWTP performing enhanced biological P removal. Future work is recommended to verify the applicability of $FeCl_3$ in the current full-scale wastewater system and assess its cost savings with $Mg(OH)_2$.

5. Acknowledgements

I sincerely thank Katherine Cochrane, Janet Ham, Phillip Meng, Einar Fridjonsson, and Brendan Graham for their ongoing support. I also appreciate the Experts and Operations team for their valuable contributions, and I am grateful to the Water Corporation Research and Development program funding and supporting this project.

6. References

Cen, X., Li, J., Jiang, G., & Zheng, M. (2023). A critical review of chemical uses in urban sewer systems. *Water Research (Oxford)*, 240, 120108–120108. https://doi.org/10.1016/j.watres.2023.120108.

Ganigue, R., Gutierrez, O., Rootsey, R., & Yuan, Z. (2011). Chemical dosing for sulphide control in Australia: An industry survey. *Water Research (Oxford)*, 45(19), 6564–6574. https://doi.org/10.1016/j.watres.2011.09.054

Kulandaivelu, J., Shrestha, S., Khan, W., Dwyer, J., Steward, A., Bell, L., Mcphee, P., Smith, P., Hu, S., Yuan, Z., & Jiang, G. (2020). Full-scale investigation of ferrous dosing in sewers and a wastewater treatment plant for multiple benefits. *Chemosphere (Oxford)*, 250, 126221–126221. https://doi.org/10.1016/j.chemosphere.2020.126221.

Rebosura, M., Salehin, S., Pikaar, I., Sun, X., Keller, J., Sharma, K., & Yuan, Z. (2018). A comprehensive laboratory assessment of the effects of sewer-dosed iron salts on wastewater treatment processes. *Water Research (Oxford)*, 146, 109–117. https://doi.org/10.1016/j.watres.2018.09.021.

Sharma, K. R., Corrie, S., & Yuan, Z. (2012). Integrated modelling of sewer system and wastewater treatment plant for investigating the impacts of chemical dosing in sewers. *Water Science and Technology*, 65(8), 1399–1405. https://doi.org/10.2166/wst.2012.019.

Water Corporation. (2019c). Wastewater Treatment Plant - Operations and Maintenance Manual. https://nexus.watercorporation.com.au/otcs/cs.exe/app/nodes/130710737

Zhang, L., Qiu, Y.-Y., Sharma, K. R., Shi, T., Song, Y., Sun, J., Liang, Z., Yuan, Z., & Jiang, F. (2023). Hydrogen sulphide control in sewer systems: A critical review of recent progress. *Water Research (Oxford)*, 240, 120046–120046. https://doi.org/10.1016/j.watres.2023.120046

Liang, Z., Sun, J., Chau, H. K., Leong, E. I.-M., Wu, D., Chen, G., & Jiang, F. (2019). Experimental and modelling evaluations of sulphide formation in a mega-sized deep tunnel sewer system and implications for sewer management. *Environment International*, 131, 105011–105011. https://doi.org/10.1016/j.envint.2019.105011

Sharma, K., Ganigue, R., & Yuan, Z. (2013). pH dynamics in sewers and its modeling. *Water Research (Oxford),* 47(16), 6086–6096. https://doi.org/10.1016/j.watres.2013.07.027