

Investigation of Oxygen Injection Station Effectiveness

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Abstract

Water Corporation implemented gaseous oxygen injection stations to combat hydrogen sulphide associated problems generated from sewage, however, they have not been assessed for many years. Dissolving oxygen into the wastewater oxidises existing sulphides and inhibits further generation. Through recent advances in spectroscopy it is possible to measure Total Dissolved Sulphides (TDS). The oxygen dissolvers on Slade St and Cresswell Rd pump stations were investigated. Each system was monitored for a period without oxygen in order to determine base conditions; and then with oxygen injection. The TDS build up on the Slade system generally agreed with the literature model and using an annual dosage of 42,500m³ oxygen reduced the TDS build up by 65%. The TDS build up on the Cresswell system significantly deviated from the model and using an annual dosage of 60,000m³ oxygen reduced TDS build up by 8%. Although oxygen injection continues to provide sulphide control, complete reduction in TDS is not possible. Further work will focus on the economic viability of oxygen injection technology and identifying potential alternative control solutions.

1. Introduction

Hydrogen sulphide is a major problem in sewage systems. One approach to control such problems is chemical dosing of the wastewater. Oxygen oxidises existing sulphides and inhibits anaerobic generation (Gutierrez et al., 2008), and has been widely used due to its cost effectiveness (Ganigue et al., 2011). Water Corporation implemented oxygen dosing stations on major pumping stations over thirty years ago. However, the overall efficiency and effectiveness of the dosing stations have not been assessed for many years.

The major problems associated with hydrogen sulphide are asset corrosion and foul odours with potential health risks. The corrosion referred to occurs at the surfaces of vulnerable structures in the sewage network, causing extensive structural damages (MMBW, 1989). The obvious characteristic of hydrogen sulphide is its “rotten egg” odour, which is detectable even at low concentrations and can be toxic (Gutierrez et al., 2008). The gas escaping into the atmosphere can trigger customer complaints and require remedial action.

1.1 Sulphide Sources

Biological and biochemical activity in wastewater, under anaerobic conditions, are the major contributors to the production of hydrogen sulphide (MMBW, 1989). Sulphides may be

directly discharged into the sewage, but more commonly originate from an oxidised form (mainly sulphate) and are generated in anaerobic conditions via reduction by sulphate-reducing bacteria (SRB) (Sharma et al., 2011). These bacteria are obligate anaerobes and reside in biofilms that form along the walls of the sewer pipes. The sulphide generated (S^{2-}) is almost completely converted and corresponds to an increase in molecular H_2S .

The sulphide generation rate is predominantly influenced by the activity of the SRB which is dependent on a number of factors (MMBW, 1989). Pomeroy's empirical equation (Eq 1) identifies the sewage biological oxygen demand and temperature as the primary factors. The model was shown to adequately predict sulphide flux on Australian systems with uncertainties of $\pm 50\%$ or more to be expected given the variable nature of wastewater (MMBW, 1989).

$$G = M [BOD_5] 1.07^{T-20} \quad (1)$$

where G = sulphide flux from wall slimes, g/m^2h
 M = specific sulphide flux coefficient generally taken as 10^{-3}
 $[BOD_5]$ = 5 day biochemical demand for oxygen, mg/L
 T = wastewater liquid temperature, $^{\circ}C$

The sulphide generation model (Eq 2) implies that the rate of sulphide generation in the wastewater body is proportional to the sulphide flux from the wall slimes and is useful in predicting average sulphide generation rates (MMBW, 1989).

$$\Delta S = \frac{4G(1+0.4D)\tau}{D} \quad (2)$$

where ΔS = change in sulphide concentration, mg/L
 τ = retention time, h
 D = internal diameter, m

1.2 Control Methods

To resolve corrosion problems the existing system can be redesigned with improved ventilation, chemical treatment or protective linings. Odour problems require some form of treatment such as bioreactor treatment or chemical addition (Zhang et al., 2008).

Figure 1 (below) summarises current chemical treatments, classified by one of four control functions – increasing redox potential to control sulphide formation, inhibition of SRB activity, chemical removal of sulphides or biological oxidation of sulphides (Zhang et al., 2008). An increase in the redox potential prevents anaerobic conditions to favour reduction of another species over sulphate. SRB activity can be inhibited with biocides, molybdates or pH elevation. Sulphides can be removed chemically via precipitation or oxidation. They can also be biologically oxidised, attributed to nitrate reducing-sulphur oxidising bacteria believed to have a significant role in oxidising the H_2S produced by SRB (Zhang et al., 2008).

1.3 Oxygen Injection

The Water Corporation uses a multiple U-tube dissolver, relying on the cascading effect of sewage in the tubes to dissolve pressurised pure oxygen. Oxygen is injected when wastewater pumps are running, maximising transfer into the liquid phase, which can be described by the two-film theory (Gutierrez et al., 2008). Diffusion is often inhibited in wastewater compared

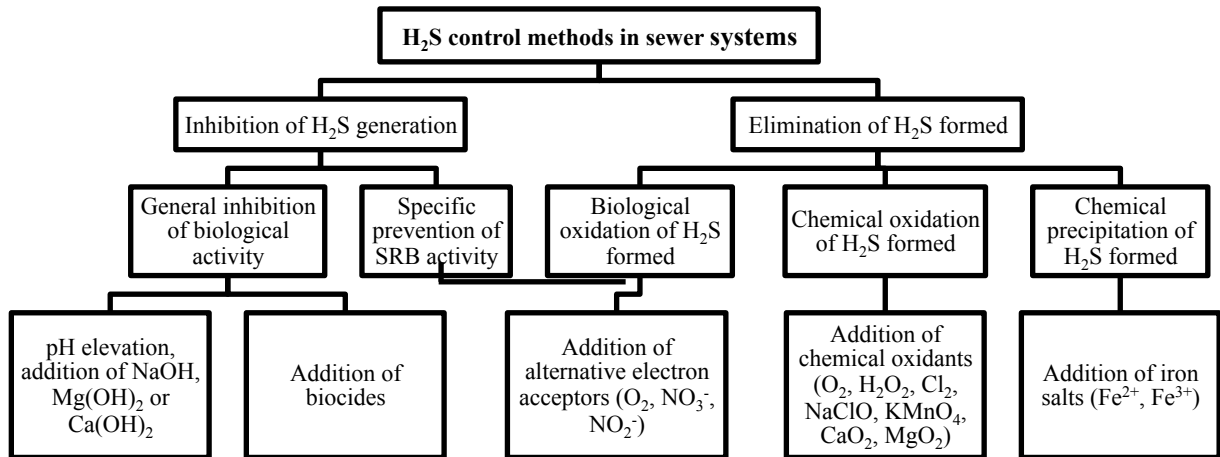


Figure 1 Summary of chemical and biological technologies for H₂S emission control in sewer systems, adapted from Zhang et al. (2008)

to pure water as impurities occupy the liquid film layer. The mass transfer driving force is the difference between equilibrium concentration and the bulk concentration of oxygen in the liquid – oxygen saturation deficit. The mass transfer rate is governed by the overall mass transfer coefficient which is dependent on a number of factors including the bubble profile, transfer surface area, flow velocity and temperature (Gutierrez et al., 2008). The total oxygen demand of the system must be determined to calculate the necessary oxygen injection rate.

2. Process

2.1 Equipment

The standard method of wastewater analysis is through collection of samples and subsequent analysis by analytical chemistry, which fails to capture the temporal variability of sewer processes. The DCM Portable Quality Monitoring Station (PQMS) was used, incorporating recent advances in spectroscopy in conjunction with standard pH techniques to measure total dissolved sulphides (TDS) in sewage on site and in real-time (Sutherland-Stacey et al., 2008). The spectrometer measures the attenuation of light in the UV-VIS spectrum. Various components of wastewater absorb light in different regions of the UV-VIS spectrum and the spectrometer detects the total absorption from the compounds present. The absorption of the bisulphide is isolated from background absorption before it is modelled to then estimate the bisulphide concentration. Bisulphide and hydrogen sulphide exist in equilibrium (Eq 3) and the TDS concentration can be mathematically derived (Eq 4) by determining the bisulphide concentration and the equilibrium position of the sewage (Sutherland-Stacey et al., 2008).

$$a = \frac{10^{-pK}}{10^{-pH}} = \frac{[HS^-]}{[H_2S]} \rightarrow TDS = [H_2S + HS^-] = \frac{a+1}{a} [HS^-] \quad (3)$$

2.2 Experimental Setup

Two oxygen dissolvers on the Slade St and Cresswell Rd pump stations on the rising mains systems, both multiple U-tube types, were tested. The wastewater from the Slade system is discharged into an intermediate bypass system which ultimately collects at Cresswell. There are two rising main sewers (and oxygen dissolvers) at Cresswell which both discharge into a

gravity sewer – only the primary system was used for this test, however, both were operated normally for the duration of the monitoring period. The gravity sewer concludes at the wastewater treatment plant. The relationship between these systems is presented in figure 2.

Each system (Slade and Cresswell) was continuously monitored. Two PQMSs were used – one station installed at an upstream location at the pumping stations prior to oxygen injection and the other at a downstream location just prior to the discharge. Each system was monitored over a week with oxygen dissolvers turned off to establish base conditions; then monitored for another week with the oxygen turned on. For the Slade system, there was sufficient time to monitor an increased oxygen injection rate. The setup is identified in table 1.

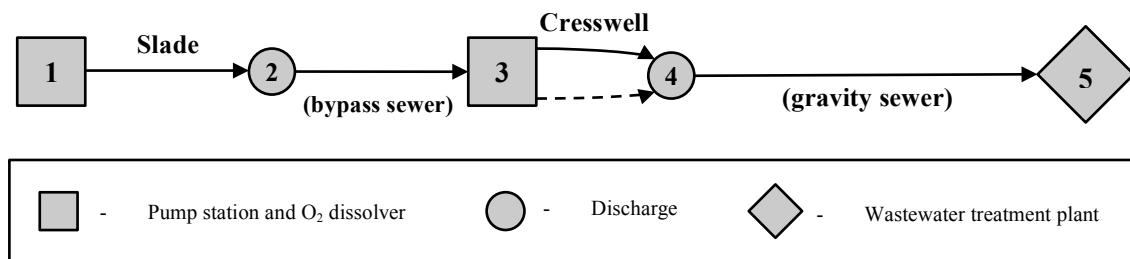


Figure 2 System diagram and location identifications

	Slade	Cresswell
Upstream location	1	3
Downstream location	2	4
Distance btwn PQMSs	2330m	1550m
Pipe diameter	0.6m	0.76m
Pump flow rate	250L/s	550L/s

Table 1 Summary of PQMS installation locations for each system

3 Results

The upstream and downstream values were differenced, accounting for retention times, to determine the TDS build up (Δ TDS) over the system. Each series was distinguished by the oxygen on or off condition and made comparable by matching the time of day of the first observations. Large variations were observed for all series, although similar trends are apparent. All dissolved oxygen readings were negligible; it is not known if the oxygen was fully consumed or mass transfer into the liquid was inefficient.

3.1 Slade

The results for the Slade system are presented in figure 4a. The baseline Δ TDS ranged between 5-11mg/L (averaging 8.29mg/L), between 0.5-9mg/L with oxygen turned on and 1-5mg/L with the increased injection rate. With maximum oxygen injection the Δ TDS was reduced on average by 65.5%. The initial injection rate was set to 14mg/L during the day and 21mg/L during the night, corresponding to an annual usage of 24,000m³. The increased injection rate was set to the maximum 32mg/L during both day and night, corresponding to an annual usage of 42,500m³. The results verify that oxygen injection continues to provide sulphide control and a higher injection rate corresponds to a greater reduction in Δ TDS. However, negligible oxygen readings and non-zero TDS readings suggest that even at

maximum injection, the Slade system consumes all available oxygen prior to the discharge. The baseline data agrees well with the model and may be used to aid the design of future control methods.

3.2 Cresswell

The results for the Cresswell system are presented in figure 4b. The baseline Δ TDS ranged between 8-22mg/L (averaging 13.73mg/L) and between 8-16mg/L when the oxygen was turned on. With oxygen injection the Δ TDS was reduced on average by 8.34%. The oxygen injection rate was set to 7mg/L during the day and 9mg/L during the night, corresponding to an annual usage of 60,000m³.

However, the baseline Δ TDS deviates significantly from the sulphide generation model, although there appear to be similar trends. This suggests that the model may still be able to describe the trend of the system, although the assumed [BOD₅] is underestimated – there are more complex processes occurring in the sewer than expected.

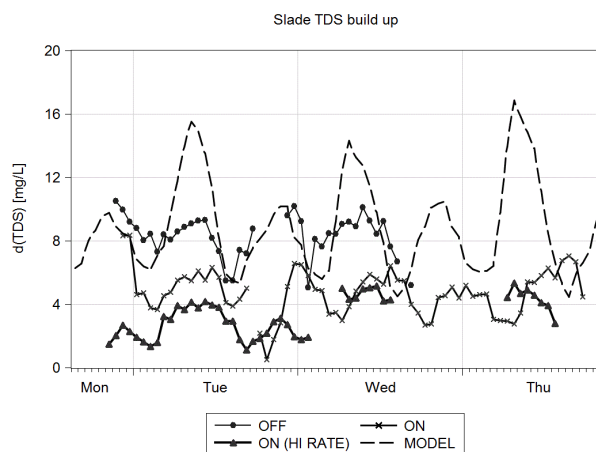


Figure 4a Results of Slade system

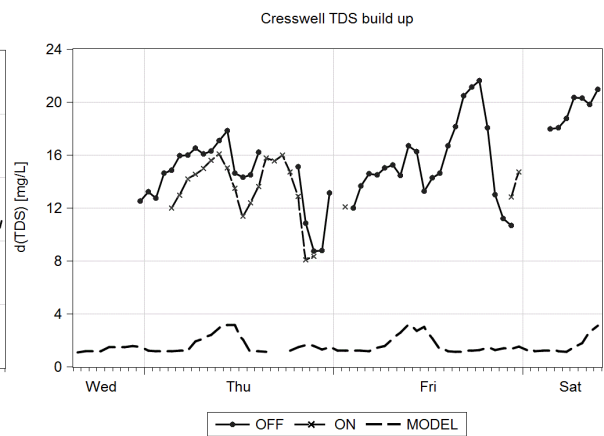


Figure 4b Results of Cresswell

<i>Calculated averages</i>		<i>Data set</i>	<i>Slade</i>	<i>Cresswell</i>
Δ TDS w/o O ₂	[mg/L]	{OFF}	8.29 (\pm 3.90)	13.73 (\pm 5.49)
Diff. in Δ TDS due to O ₂	[mg/L]	{OFF – ON}	-3.17 (\pm 2.98)	-1.39 (\pm 1.11)
%Diff.		{OFF – ON}	-38.1	-8.34
Diff. in Δ TDS due to O ₂	[mg/L]	{OFF – ON(HI RATE)}	-5.17 (\pm 4.24)	
%Diff.		{OFF – ON(HI RATE)}	-65.5	

Table 2 Summary of results comparing series with and without oxygen

3.3 Discussion

The primary sources of experimental errors include the equipment faults and uncertainty of the equilibrium position. Large errors are possible for a single reading when the pH is below the equilibrium position, as this means the majority of sulphides are in the invisible H₂S form (Sutherland-Stacey et al. 2008). These errors are compounded since the results compare two series which uses the readings from the two different machines. Furthermore, the pH probe on the upstream PQMS malfunctioned prior to the Slade monitoring, however the profile was

recreated using grab samples. At Cresswell, a long sampling tube was used at the discharge location and there was uncertainty whether fresh samples were drawn which may have impacted the quality of the readings and results.

TDS was calculated at the conclusion of the monitoring period and thus not used to determine the initial oxygen injection rates, which were underestimated. Using the results, the theoretical optimal day and night injection rates are 50mg/L and 90mg/L, respectively, at Slade and 25mg/L and 35mg/L at Cresswell. However, these injection rates are unachievable on the current dissolving stations. Increasing the injection station orifice sizes without decreasing the pressure may solve this problem. Further monitoring on Cresswell with increased oxygen injection rates would be beneficial to understand the impacts of significantly lower retention times and larger wastewater volume on the oxygen demand.

4. Conclusions and Future Work

This study found that oxygen injection continues to provide sulphide control in sewer systems. However, complete sulphide reduction cannot be achieved on the systems tested even though the oxygen usage, and hence operating cost, is quite significant. The cost-benefits analysis is currently being conducted and further work aims to identify factors influencing oxygen injection performance and potential alternative solutions. A recent survey of the Australian water industry has shown large shifts to pH elevation chemical dosage, such as sodium hydroxide, which provides a basis for future investigation (Ganigue et al., 2011). Free nitrous acid, formaldehyde, microbial fuel cells and SRB lysing phages have been identified as potential cost-effective chemical treatment solutions (Zhang et al., 2008).

5. Acknowledgements

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6. References

- Ganigue, R. et al., 2011. Chemical dosing for sulfide control in Australia: An industry survey. *Water research*, 45(19), pp.6564–74.
- Gutierrez, O. et al., 2008. Evaluation of oxygen injection as a means of controlling sulfide production in a sewer system. *Water research*, 42(17), pp.4549–61.
- Melbourne and Metropolitan Board of Works, 1989. Hydrogen Sulphide Control Manual.
- Sharma, K.R. et al., 2011. Impact of chemical dosing of sewers on WWTP performance. *Water*, 38(1), pp.88–91.
- Sutherland-Stacey, L. et al., 2008. Continuous measurement of dissolved sulfide in sewer systems. *Water science and technology* □ a journal of the International Association on Water Pollution Research, 57(3), pp.375–381.
- Zhang, L. et al., 2008. Chemical and biological technologies for hydrogen sulfide emission control in sewer systems: a review. *Water research*, 42(1-2), pp.1–12.