ON-LINE CONTROL OF MAGNESIUM HYDROXIDE DOSING FOR SULFIDE MITIGATION IN SEWERS

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ABSTRACT

Magnesium hydroxide (Mg(OH)₂) is commonly dosed in sewer systems to control corrosion and odour problems by preventing sulfide transfer from the liquid to the gas phase. Current dosing practices do not take the dynamics of sewage flow and sulfide production into consideration. This paper presents the development of an on-line control methodology for the optimised dosing of Mg(OH)₂, based on pH measurement and the wastewater buffer capacity. Sewage acidification due to fermentative processes is also taken into consideration. Simulation results showed an improved pH control with reduced chemical consumption.

INTRODUCTION

The control of hydrogen sulfide in sewer systems is nowadays one of the main challenges for the Australian water utilities. Sulfide is produced in the liquid phase of sewer systems (mainly pressure mains) under anaerobic conditions by sulfate reducing bacteria (SRB) (Hvitved-Jacobsen 2002; Melbourne 1989). The transfer of hydrogen sulfide from the liquid to the gas phase leads to serious sewer corrosion, which accelerates the depreciation of sewer assets (WERF 2007). In Australia alone, this has an estimated cost of about $100M per year. As well as this, hydrogen sulfide causes odour nuisances and has important health concerns due to its high toxicity (Boon 1995).

There are currently several methods to control this problem, with chemical dosing being widely used. According to a recent survey conducted among the major water utilities in Australia, magnesium hydroxide is used at more dosing sites than any other chemicals (Ganigué et al. 2011). Mg(OH)₂ prevents sulfide transfer from the liquid to the gas phase by increasing the pH of the sewage (Gutierrez et al. 2009). Generally, H₂S is present in the liquid phase as an equilibrium of two sulfide species, H₂S and HS⁻. The rise of pH shifts the equilibrium, reducing the concentration of H₂S in the liquid phase and hence preventing its release to the sewer atmosphere. The maximum pH achievable by Mg(OH)₂ dosing is approximately 9.0-9.2 due to its limited solubility in water (WERF 2007). At such pH levels, the percentage of H₂S in the liquid is less than 1%. According to Gutierrez et al. (2009), long-term pH elevation to 8.6–9.0 reduces SRB activity by 30%-50%. Methane is a greenhouse gas with a warming potential 21-23 times higher than carbon dioxide (IPCC (2006)). It is also produced in sewer systems (Guisasola et al. 2008), but its generation is prevented at pH levels around 8.6-9 (Gutierrez et al. 2009).

The way chemical dosing is conducted has not only a major influence on the effectiveness of sulfide control strategies, but also significant cost implications. Controlling chemical dosing in rising mains is very challenging due to the plug-flow behaviour of the system. According to the same industrial survey (Ganigué et al. 2011), flow-paced or profiled dosing are used at the majority of the Mg(OH)₂ dosing sites. These are commonly based on empirical guidelines developed through experience (de Haas et al. 2008). However, sewers have a dynamic behaviour, and these control methodologies could easily lead to over or under dosage. On-line dosing control has great potential benefits, allowing improved control performance and a reduction of chemical costs (Sharma and Yuan 2009). In this light, this work aims to develop an on-line control methodology for the optimised dosing of Mg(OH)₂ for sulfide mitigation in sewers.

CONTROL DESIGN

Dosing location choice

The main aim of magnesium hydroxide dosing for sulfide control is to rise the pH to reduce sulfide transfer from the liquid to the gas phase. In this respect, the dosing control system has to guarantee stable sewage pH close to the desired set-point at the discharge point, with minimal chemical consumption.

The optimal dosing location will largely depend on specific conditions of each system. Dosing Mg(OH)₂ at the discharge point would be simpler in terms of control. However, a dosing location at the beginning of the pipe minimizes sulfide transfer during the transport (e.g. through air valves), preventing possible odour complaints. Moreover, as stated before high pH levels (8.6-9) decreases sulfide production and stops methane generation.
(Gutierrez et al. 2009). This is beneficial from the environmental point of view due to the reduction of sulfide and methane (a potent greenhouse gas) emissions. Furthermore, biological activity reduction may also minimise sewage acidification due to fermentative processes, reducing the amount of magnesium hydroxide to be dosed.

**Control scheme**

Given a dosing location at the beginning of the pipe, an on-line control methodology for the optimised dosing of magnesium hydroxide was designed, and is depicted in a schematic way in Figure 1.

The \( \text{Mg(OH)}_2 \) dosing controller has three main components. The first one aims to determine the amount of magnesium hydroxide required to increase the sewage pH to a desired set-point. This amount mainly depends on the sewage pH and its buffer capacity. Sewage pH is very dynamic throughout the day (as shown in Figure 2), but can be easily monitored on-line using common and inexpensive sensors.

On the contrary, buffer capacity of the wastewater can not be measured on-line, but needs to be determined by titration.

To investigate this, sewage samples were collected at different times of the day from the wet well of a rising main from Allconnex Water, located at the Gold Coast. These samples were titrated with sodium hydroxide (NaOH) (0.1M) using an automatic titration device. Results are depicted in Figure 3.

Sulfide production and fermentation are two of the main biological processes occurring during the transport of sewage. These biotransformations have an impact on sewage pH and need to be taken into consideration when aiming at a proper pH control. In this light, the second component for the control algorithm is a mathematical model developed to predict the net proton production during the transport, as a function of the pipe dimensions and the hydraulic retention time of the sewage. Based on that, the controller can estimate the additional amount of magnesium hydroxide to balance pH decrease due to the biological activity.

These two components constitute the core of the control algorithm and have a feedforward nature because the control action is determined based on the measurement of perturbations rather than the current output of the controlled variable (in this case pH at the discharge point).

Although effective and efficient, feedforward controllers are subject to a certain degree of uncertainty. All disturbances need to be taken into account and predicted accurately, otherwise the controller may perform poorly. To prevent this, a feedback loop was included as the third component.
of the control algorithm. This feedback loop aims to automatically adjust the Mg(OH)$_2$ dosing based on the long-term overall performance of the controller. This can be quantified by calculating the weighted moving average of the pH at the discharge point. In this case, a period of 7 days was found adequate, with the more recent pH measurements being given a higher importance.

SIMULATION STUDY

Scenario definition
The on-line control methodology was tested in a simulation study to assess its performance. This was conducted using the SeweX model, a dynamic mathematical model for the simulation of sewer systems (Sharma et al. 2008).

A scenario was defined with Mg(OH)$_2$ being dosed to a rising main with a length of 828 m and a diameter of 150 mm. Dosing was conducted at the pumping station of the rising main. On-line pH measurement in the wet well and the discharge point were available for control purposes, as well as wastewater flow. The aim of the dosing was to reach a pH of 9 at the discharge point. Simulations were run for 21 days, with dosing occurring during the last 14 day period.

The performance of the on-line control methodology was compared with a classical flow-paced control (the amount of chemical delivered is proportional to wastewater flow). Three different dosing regimes were simulated: low, medium and high.

Simulation results
Figure 4 depicts the sewage pH at the discharge point for the on-line control, as well as the flow-paced control at three different dosing levels.

The performance of the four different control methodologies is further analysed in Table 1.

Table 1. pH at the discharge point (days 14-21): Maximum, minimum, average and standard deviation.

<table>
<thead>
<tr>
<th></th>
<th>Flow-paced (low)</th>
<th>Flow-paced (medium)</th>
<th>Flow-paced (high)</th>
<th>On-line control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. pH</td>
<td>9.01</td>
<td>9.40</td>
<td>9.55</td>
<td>9.14</td>
</tr>
<tr>
<td>Min. pH</td>
<td>8.07</td>
<td>8.77</td>
<td>9.01</td>
<td>8.90</td>
</tr>
<tr>
<td>Average pH</td>
<td>8.56</td>
<td>9.03</td>
<td>9.22</td>
<td>9.01</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.23</td>
<td>0.15</td>
<td>0.13</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Results show that flow-paced control was not capable of maintaining pH within a close vicinity of the set-point of pH 9. Flow-paced control at a low rate was not able to meet the set-point at the discharge point, whereas at a high dosing rate, the pH was consistently above the set-point. Regarding the flow-paced strategy with intermediate rates, it kept pH on average around 9. However, the pH fluctuated greatly from about pH 8.8 to pH 9.4.

On the other hand, the on-line control allowed keeping the discharge pH close to the desired set-point of pH 9, with minimal variations. The pH level was slightly higher during the first days the on-line control was in place (days 7-10) due to the feedback loop, which progressively adjusted the dosing based on the overall performance.
Although flow-paced control with a medium dosing rate during the day was able to achieve satisfactory performance, it is important to highlight that sewer systems are highly dynamic and no optimal pacing rate would be valid for every day. On the contrary, the on-line control methodology adjusts the dosing automatically based on the current state of the system.

As stated before, the aim of magnesium hydroxide dosing is to prevent the transfer of H$_2$S from the liquid to the gas phase. In order to further analyse the effectiveness of the four different control methodologies for sulfide mitigation, concentration of dissolved H$_2$S in the liquid at the discharge is depicted in Figure 5.

![Figure 5. H$_2$S concentration in the liquid phase.](image)

Figure 5 shows that H$_2$S levels in the liquid phase for the flow-paced control at a low dosing rate were high, with concentrations up to 0.6 mgS/L. This was due to the relatively low pH reached, despite the dosing control (minimum pH was around 8). On the contrary, the other three control methodologies (both medium and high dosing rate flow-paced controls and the on-line control) achieved much lower H$_2$S levels in the liquid phase, with concentrations always below 0.15 mgS/L.

![Figure 6. Dosing rates and pH profiles during one day of flow-paced (medium) and on-line control.](image)

The good pH adjustment of the on-line control kept H$_2$S concentration in the liquid phase very stable, around 0.05 mgS/L. The flow-paced control methodology at intermediate dosing rates achieved similar pH on average, although pH fluctuated significantly during the day (from pH 8.77 to pH 9.40). Hence, H$_2$S concentration in the liquid varied accordingly from 0.03 mgS/L to about 0.15 mgS/L. This clearly shows that a better pH control also entails a decrease on H$_2$S levels. This reduction is not negligible, considering the fact that, in gas-liquid equilibrium at 25°C, the gas phase H$_2$S concentration would be approximately 50 ppm and 17 ppm, at dissolved H$_2$S concentrations of 0.15 to 0.05 mgS/L, respectively.

To gain a deeper insight on this analysis, Figure 6 presents the simulated dosing rate profile for the flow-paced control at an intermediate dosing rate (medium) and on-line control on day 20. The same graph also depicts sewage pH at the wet well and pH level at the discharge point.
As shown in Figure 6, dosing rate for the flow-paced strategy was constant around 90 kgMg(OH)$_2$/d. The amount of Mg(OH)$_2$ dosed was not sufficient to reach pH 9 during periods with very low sewage pH (around pH 7). On the contrary, it was excessive when pH of the wastewater at the wet well was 8-8.5, leading to pH levels at the discharge point around pH 9.3-9.4, much higher than the desired set-point. On the contrary, on-line control adjusted the dosing rate to the wastewater characteristics. Dosing rates of 115-120 kgMg(OH)$_2$/d were applied when sewage pH was low (pH 7-7.5), whereas this was decreased to less than 75 kgMg(OH)$_2$/d at high sewage pH (pH 8-8.5). This allowed controlling pH on a more stable way.

Such an improvement on pH control has also an impact on the dosing costs. This can be assessed in Figure 7, where the annual and volumetric Mg(OH)$_2$ dosing for the four strategies are presented.

From Figure 7, it can be clearly seen that flow-paced control methodology (low) had the lowest chemical consumption, with an average volumetric dosing around 50 gMg(OH)$_2$/m$^3$ of wastewater. However this dosing level was not sufficient to raise pH to the desired set-point and H$_2$S levels in the liquid phase were high at discharge (see Figure 5). Comparing the other three cases, where the desired set-point was reached, on-line control had a reduced chemical consumption (65 gMg(OH)$_2$/m$^3$) in comparison with the flow-paced control at a medium and high dosing rate (70 gMg(OH)$_2$/m$^3$ and 80 gMg(OH)$_2$/m$^3$, respectively).

Comparing the on-line control dosing with the flow-paced control (medium), chemical consumption was reduced by about 10%. Since pH sensors are widespread and relatively inexpensive, on-line control can be implemented with minimal capital investment. In this respect, on-line control may lead to significant savings, especially in large systems.

**FULL-SCALE TRIAL**

At present, this control methodology is being tested at the Queensbury Sewage Pumping Station (SPS) operated by SA Water (Adelaide, South Australia). The rising main has a total length of 5290 m and a pipe diameter of 600 mm. Magnesium hydroxide is dosed at the pumping station when sewage is pumped to the main. With regards to the instrumentation, flow and pH measurements are available at both the pumping station and the discharge point. The magnesium hydroxide flow is also monitored. All these on-line signals are collected in a Remote Telemetry Unit (RTU), which controls the dosing. A scheme of the system is depicted in Figure 8.

This pumping station collects wastewater from different gravity sewers and conveys it to the Bolivar wastewater treatment plant. The average dry weather flow is about 12 ML/d, with the hydraulic retention time typically ranging from 1 to 8 hours, depending on the time of the day. Sewage flow rate is shown in Figure 9.

Analytical results from a sampling campaign conducted in August 2011 showed total dissolved sulfide concentrations higher than 10 mgS/L at the discharge point of the Queensbury pressure main during long hydraulic retention times. At pH 9 and 25°C, gas phase H$_2$S concentration could reach values of about 30 ppm, highlighting the importance of proper pH control.

![Figure 8. Scheme of Queensbury SPS](image)

![Figure 9. The sewage flow rate at the Queensbury SPS.](image)
The implementation and validation of the on-line control strategy at the Queensbury SPS is currently ongoing and results will be presented at the conference.

**CONCLUSION**

An on-line control scheme for the optimised dosing of Mg(OH)₂ in sewers was designed based on pH measurement at the start of the rising main. The simulation study demonstrates that on-line control allows a much better pH control, minimising pH variation and reducing the total quantity of chemical dosed.

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