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Performance of sanitary sewer collection system odour control devices operating in diverse conditions

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ABSTRACT

Controlling odours from sanitary sewer systems is challenging as a result of the expansive nature of these systems. Addition of oxidizing chemicals is often practiced as a mitigation strategy. One alternative is to remove odorous compounds in the gases vented from manholes using adsorptive media. In this study, odour control devices located at manholes were observed to determine the ability of these systems to reduce hydrogen sulphide from vented gases. The odour control devices incorporated pressure regulation to control gas flow out of manhole covers and adsorptive media to remove hydrogen sulphide in the vented gases prior to release. Pressure regulation was accomplished using a variable volume bladder and two pressure relief valves that permitted gas flow when pressures exceeded 1.3 to 2.5 cm water column. The reduction in gas flow vented from manholes was intended to extend the service life of the adsorptive media, as compared with odour control devices that do not incorporate pressure modulation. Devices were deployed at four locations and three adsorptive media were tested. Although measured collection system hydrogen sulphide concentrations varied from zero to over 1,000 ppm, the removal rates observed using odour control devices were typically above 90%. The lower removal rates observed at one of the sites (50.5 ± 36.1%) appeared related to high gas flow rates being emitted at this location. Activated carbon was used in most of the tests, although use of iron media resulted in the highest removal observed: 97.8 ± 3.6%. The expected service life of the adsorptive media contained within the odour control devices is a function of site-specific hydrogen sulphide concentrations and gas flow rates. The units used in this study were in service for more than 8 to 12 months prior to requiring media replacement.

Key words | collection system, hydrogen sulphide, manhole, odour control, sanitary sewer

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INTRODUCTION

Sanitary sewer collection systems are dynamic systems with varying flow rates, temperature, pressure, water quality, and biological activity. The gases vented from such systems cause health and safety concerns as well as nuisance odours (Boon 1995; Boon *et al.* 1998). Gas flow rates within collection systems and flow rates of gases being vented from such systems are variable and dependent on collection system characteristics and operation (Pescod & Price 1982; Ward *et al.* 2011a). In addition, water-saving devices and water conservation practices have exacerbated collection system odours by increasing septicity (Tchobanoglous *et al.* 2003). Oversizing collection system components to accommodate build-out conditions can also result in increased septicity that contributes to generation of odorous gases.

Hydrogen sulphide (H_2S) is a major contributing factor for odours and for the corrosive atmosphere found within collection systems (US EPA 1974). Hydrogen sulphide is the most commonly measured collection system gas compound, although there is value in measuring other odour-contributing parameters such as volatile organic compounds (Sivret & Stuetz 2012). Multiple strategies are used to address collection system emissions and odours. Chemical addition is widely used but is expensive;

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chemical options include nitrates, chlorine, metal salts, hydrogen peroxide, and potassium permanganate (Zhang *et al.* 2008). Addition of compressed air or oxygen into the liquid phase and pH control are other options (Nielsen *et al.* 2008). Biological treatment systems have been used successfully for removal of H_2S (Easter *et al.* 2005). Another alternative is to reduce odour-causing constituents from the vented gases (Mansfield *et al.* 1992; Boon 1995).

Odours emitted from collection systems have long been a problem in cities (US EPA 1974). Recent efforts have advanced understanding of air flow in collection systems through direct observation and modelling (Parker & Ryan 2001; Edwini-Bonsu & Steffler 2006; Madsen *et al.* 2006; Vollertsen *et al.* 2011; Ward *et al.* 2011a, b; Wang *et al.* 2012). However, most activities aimed at reducing odours are initiated by customer complaints (Sivret & Stuetz 2012). Development of a comprehensive odour control program requires adoption of multiple strategies to prevent and reduce odours through pretreatment programmes, grease trap management, operation of system components (e.g. pump stations), chemical dosing, and other approaches. Development of new odour control strategies are needed to implement such a comprehensive plan.

One potential problem with use of adsorptive media to remove H_2S from vented gases is that the media requires frequent replacement due to the large volumes of gases present in collection systems and the limited mass adsorption capacity of most media. Here, vented gas flow was minimized to reduce odours and to decrease media replacement frequency. The objectives of this study were to quantify the removal efficiency of an odour control system at four sites, to investigate the use of three media, and to estimate the media replacement schedule for the devices.

METHODS

The study was conducted at four sites (Table 1). Site selection was based on complaints from nearby residents and input from system owners. The exact site locations are not described to protect the anonymity of the system owners.

The Manhole Odor Eliminator (Inventive Resources Inc., Salida, CA, USA), consisting of manhole inserts located directly below manhole access covers, was evaluated for the ability to remove H_2S from vented sewer gas (Figure 1). A variable volume bladder, in fluid communication with sewer gases, was used to accommodate pressure regulation and air flow fluctuations. A low-setting pressure relief valve allowed sewer gases to pass only when the bladder was full and the pressure exceeded approximately 1.3 cm water column. Vented gases were forced through an adsorptive granular media filter and entered a treated air chamber prior to release. A pressure relief valve with a higher setting, intended to prevent high pressure conditions from developing in the collection system, allowed vented gas to circumvent the adsorptive media prior to release when the pressure exceeded approximately 2.5 cm water column. This second pressure relief valve served as a redundant safety mechanism. Adsorptive media consisted of 0.02 m^3 of activated carbon (Carbon Activated Corp., Compton, CA, USA), iron sponge (Connelly-GPM, Chicago, IL, USA), or zeolite. Initial tests for Sites A-1 and A-2 were carried out using activated carbon (AC). Subsequent tests were performed with iron media at Site A-1 and zeolite at Site A-2.

Hydrogen sulphide (H_2S) was measured using Jerome 860 meters that automatically collect and record data with a recommended range of 0–200 ppm (by volume) with occasional use in atmospheres with concentrations as high as 1000 ppm (Arizona Instrument LLC, Chandler, AZ, USA). Concentrations above 200 ppm are not recommended to protect the meter from corrosion. Meters

Table 1 | Descriptions of sites where odour control devices were tested

Site	Media tested	Site location	Description
Site A-1	AC[a], iron	Central California, USA	1.22 m dia. interceptor sewer, constructed 5 years ago, Sites A-1 and A-2 are located at adjacent manholes, residential area with small commercial establishments
Site A-2	AC, zeolite		
Site B	AC	West Nevada, USA	0.91 m dia. gravity sewer, hotel/casino
Site C	AC	Central California, USA	0.61 m dia. gravity sewer, university campus

[a]AC = activated carbon.

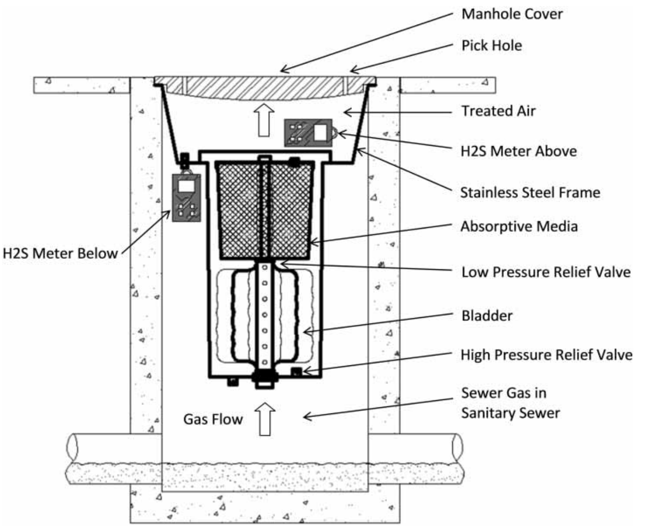

Figure 1 | Schematic of an odour control device placed in a manhole. The device was fabricated from HDPE, stainless steel, and other corrosion resistant materials. The odour control device functioned by reducing gas flow from manholes and treating vented gases with adsorptive media.

were placed above and below the odour control devices. The H_2S meter below the unit was placed at the bottom of the stainless steel frame, and not lower, to protect the instrument from coming into contact with the sewage flow. The stainless steel frame provides a relatively tight but imperfect fit with the manhole metal frames that are typically a bit uneven due to corrosion. As a result, a small quantity of the sewer gas is allowed to flow through the manhole frame and the H_2S meter below provides a reasonable representation of the gas composition in the sanitary sewer. However, the location of the H_2S meter below the device inlet may lead to some underestimation of the H_2S removal rates. Meters were calibrated in accordance with manufacturer's recommendations prior to each deployment. Meter calibration was checked at the end of each measurement period.

RESULTS AND DISCUSSION

Collection system H_2S concentrations varied between the different sites with mean values ranging from 6 to 391.7 ppm (Table 2). Although Sites A-1 and A-2 are located on the same interceptor sewer and are only 460 m apart, these two manholes emit gases with very different H_2S concentrations. Site A-2 is in the middle of a straight section of pipe, while Site A-1 is located closer to a pipe bend. The mean H_2S concentrations at Site A-1 are consistently higher than the values observed at Site A-2. Collection system mean H_2S concentrations at Sites B and C were lower than the values observed at Site A-2 and much lower than values observed at Site A-1. The mean H_2S concentrations observed above the odour devices were less than 10 ppm for all sites except Site A-1 when AC was used.

The H_2S concentration time series for Sites A-1 and A-2 were a function of the time of day and the operation of collection system pump stations (Figure 2). Although Site A-1 had consistently higher H_2S concentrations than Site A-2, the two sites demonstrated similar time-dependent H_2S patterns. The interceptor sewer on which Sites A-1 and A-2 are located receives flow from a pump station that is typically operated once per day. Operation of the pump station is controlled by a timer and peak H_2S events coincide with pump operation. In addition, at both sites H_2S concentrations are generally lower at night and higher during the day. The H_2S concentrations at Site A-1 exceeded the 1000 ppm upper limit of the H_2S sensor during peak events. Tests were initially conducted at Sites A-1 and A-2 using activated

Table 2 | Summary statistics for measured H_2S below and above manhole odour control devices[a]

			H_2S below unit (ppm)				H_2S above unit (ppm)			
Site	Media	N	Mean	Std dev	Min	Max	Mean	Std dev	Min	Max
A-1	AC[b]	1,8872	391.7	219.5	28.4	1000.0	17.8	43.4	0.0	473.8
A-1	iron	2029	251.7	115.8	20.0	967.4	7.6	18.4	0.0	230.3
A-2	AC	20,230	41.7	49.2	0.0	730.4	4.1	11.8	0.0	293.5
A-2	zeolite	2030	20.3	14.4	0.9	63.5	3.2	6.0	0.0	44.9
B	AC	3549	9.7	4.8	0.9	34.4	4.3	3.7	0.0	17.1
C	AC	2778	6.0	0.8	4.7	10.3	0.8	0.7	0.0	3.1

[a]Only includes data recorded in the reportable range of 0–1000 ppm.
[b]AC = activated carbon.

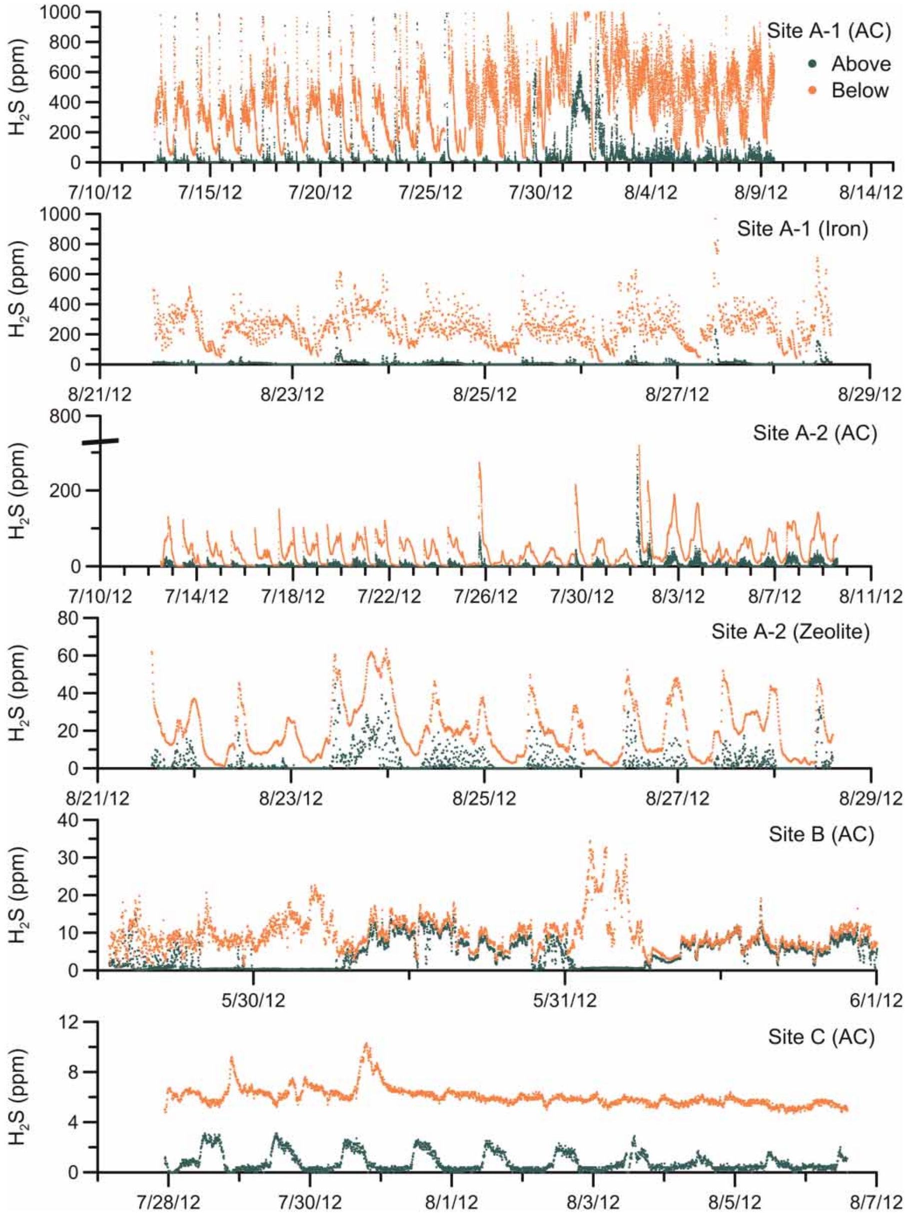

Figure 2 | Time series for H_2S observed above and below manhole odour control devices. The media used are shown in parentheses following the site name (AC = activated carbon).

carbon, and then the media at both sites was replaced and a subsequent test was performed. For the second test iron media was used at Site A-1 and zeolite was used at Site A-2. During the second set of tests with the iron media and zeolite the collection system H_2S at both sites decreased. However, the time-dependent pattern was similar to what was observed in the initial set of tests.

The time-dependent H_2S concentration patterns at Sites B and C were different than those observed at Sites A-1 and A-2. Although only a limited amount of data was collected for Site B, the H_2S concentrations appear higher at night than during the day. The unusual odour patterns at Site B may be the result of this site being located next to a casino and not located in a residential area. The collection system H_2S concentrations at Site C do not appear to have time-dependent characteristics. This site is located at a university campus and the collection system may have characteristics that differ from a system located in a residential area. Although some of the sites had consistent temporal H_2S patterns, the results varied by site. We are collecting additional data to confirm these patterns and to determine if the patterns change seasonally.

In most cases the odour control device reduced the H_2S concentration such that the H_2S concentrations above the units were lower, but had a similar response curve to the H_2S concentrations in the collection system (Figure 2). At Site B, collection system H_2S was high from approximately midnight to 6 am. During that time H_2S removal was near 100%. During the day, however, H_2S removal was minimal. During deployment of the devices at Site B crews noted significant air flow from the manhole. At Site C there are peaks in the H_2S concentration above the device that are not mirrored in the collection system H_2S concentrations. These peaks occurred during the day when collection system flow rates are higher. The peaks were lower on 3–4 August, Saturday and Sunday, which corresponds with lower occupancy at the university. In general, the relationship between vented and sewer gas H_2S concentrations was not strong (typically $R^2 < 0.5$).

High removal of H_2S was observed at most sites, although variability was observed, with mean removal ranging from 50.5 to 97.8% for the six test runs (Table 3). The highest removal was obtained using the iron adsorptive media at Site A-1 (97.8%). The lowest standard deviation of 3.6% was also observed at Site A-1 with the iron media, indicating that the most stable performance occurred during this test. The lowest removal was observed at Site B (50.5%). A possible causative factor in the low H_2S removal observed at Site B is the high air flow rate. Although the removal rate of 86.8% observed at Site C were at the low end of the range (Table 3), the H_2S concentrations at this location were lower than what was observed at the other sites (Table 2). Correlations between site conditions (time of day, ambient temperature, sanitary sewer H_2S concentration) and H_2S removal rates indicate site-specific patterns. For example, a preliminary investigation suggested that H_2S concentrations were more strongly related to ambient air pressure than temperature.

In addition to reducing H_2S in the vented gas, the manhole odour devices tested reduce the vented gas flow rates, which should also reduce the frequency of media replacement. In this study ventilation rates were not measured; however, values for similarly sized sewer pipelines are available in the literature although these flow rates apply to manholes that do not have gas flow dampening devices. For example, Ward *et al.* (2011a) measured air flow rates in four collection systems and found that air flow in the headspace ranged from 23 to 840 $L\,s^{-1}$ for pipes ranging in diameter from 0.61 to 2.5 m. The ventilation flow rates in and out of manholes measured by Ward *et al.* (2011a) were much lower, ranging from 0 to 29 $L\,s^{-1}$, although the maximum flow rate out of manholes observed was 2.8 $L\,s^{-1}$. In the current study, the pipe diameter ranged from 0.61 to 1.22 m, within the range of pipe sizes observed by Ward *et al.* (2011a).

Although the odour control devices under study reduce the quantity of gases vented, the reduced flow rates cannot be definitively determined because gas flow reductions are based on settings of the air release valves that allows slightly pressurized gases to vent through the adsorptive media. Using an AC mass of 9.0 kg per odour control device (M_{AC}), a conservative adsorptive capacity (q_e) of 0.10 kg H_2S kg^{-1} AC (Abatzoglou & Boivin 2009), and H_2S density (ρ_{H_2S}) of 1.36 $kg\,m^{-3}$, relationships were developed between vented gas flow rates (Q, $L\,s^{-1}$), H_2S removal (ΔH_2S, ppm by volume), and unit service life (Δt, d), as shown in Figure 3 and calculated using Equation (1):

$$Q = \frac{11{,}574 \times M_{AC} \times q_e}{p_{H_2S} \times \Delta H_2S \times \Delta t} \quad (1)$$

Using the flow rates from Ward *et al.* (2011a) as a guideline of the magnitude of ventilation through manhole covers and the H_2S removal observed in this study (Figure 2), it is possible to estimate the service life of the units using Figure 3. For example, for a unit removing approximately 100 ppm H_2S, the expected service life is one year as long as the average flow rate is 0.2 $L\,s^{-1}$. For an average flow rate of 2.8 $L\,s^{-1}$ and an H_2S removal of 100 ppm H_2S, the expected service life is only approximately 30 days. Without the flow dampening functionality of the odour control device, the adsorptive media is in contact with the entire air flow in the pipe, which can be orders of magnitude higher than the ventilation flow rates through the manhole (Ward *et al.* 2011a). The data shown in Figure 3 suggest

Table 3 | Removal of H_2S as a result of manhole odour control devices[a]

		H_2S removal (%)			
Site	Media	mean	std dev	min	max
A-1	AC[b]	96.6	5.6	46.7	100.0
A-1	iron	97.8	3.6	68.2	100.0
A-2	AC	94.9	8.0	4.3	100.0
A-2	zeolite	90.1	15.8	16.2	100.0
B	AC	50.5	36.1	−33.1	99.5
C	AC	86.8	12.2	41.5	100.0

[a]Only includes data recorded in the reportable range of 0–1000 ppm.
[b]AC = activated carbon.

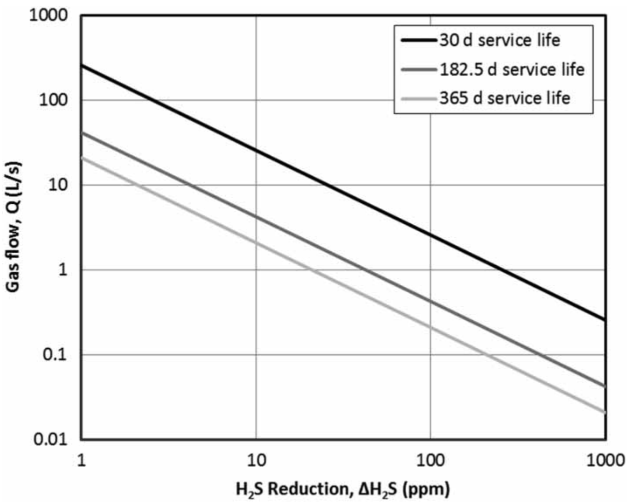

Figure 3 | Predicted relationships between vented gas flow, H_2S removal, and media service life for odour control devices containing 9 kg activated carbon (0.10 g H_2S g^{-1} AC).

that reducing the gas flow rate by an order of magnitude could potentially extend the media replacement schedule from 1 month to over a year. Better information regarding vented gas flow rates for sanitary sewer is needed to better predict performance of odour control devices.

Field data corroborate the estimates contained in Figure 3. Of the odour control devices that were deployed as part of this study, the units have been in service for 8 to 12 months without requiring media replacement. Media replacement is typically performed for these types of devices following complaints from residents and/or owners. The owner of the device deployed at Site B did report that odours at that site are intermittent, but much lower than what was previously observed and infrequently detected. We have observed a modest decrease in removal performance over time. In a long-term trial conducted at Site A-1 during the winter, we observed an approximately 4% decrease in H_2S removal over a 4 month period.

CONCLUSIONS

The results demonstrate that manhole odour control devices utilizing flow dampening and adsorptive media can be effective at reducing H_2S in gases vented from sanitary sewer collection system manholes. The odour control devices fit into existing manholes, and offer an economical solution to manhole odour issues. Incorporation of gas flow moderation reduces the amount of gas that comes into contact with adsorptive media, reducing the frequency of media replacement. Preliminary testing suggests that activated carbon and iron adsorbents are highly effective for H_2S control. On-going project activities include measurement of vented gas flow rates and continued monitoring of H_2S concentrations at sites to clarify seasonal impacts and the impacts of long-term performance. The potential effect that these odour control devices have on the collection system environment is being studied as well.

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