

Sewer catchment effects on wastewater and biosolids odour management

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ABSTRACT

The composition of wastewater in sewer catchments is known to affect the performance of wastewater treatment plants (WWTPs). However, there is limited knowledge as to how catchment characteristics, such as types of catchment industries, impact odour emissions from downstream sludge processing and biosolids management. Odorous emissions from biosolids processing at WWTPs can represent a significant community impact when the local population is exposed to odours. The main odorants emitted from biosolids are volatile sulfur compounds (VSCs), however, volatile organic compounds (VOCs) in emissions may also be perceptible after the removal of VSCs in odour abatement systems. Types of compounds present in emissions throughout biosolids processing at five WWTPs of varying sizes and levels of treatment (primary only and primary and secondary) were analysed. The ratio of total VSCs to VOCs in emissions, and the sensorial importance of each class varied between the sites. As a number of the VOCs in emissions were of industrial origin, this variation is likely dependent on industrial flows into the upstream sewer catchment. The impact of different emission compositions on both activated carbon and biologically based odour abatement systems were discussed.

Key words | biosolids, odour, sewer catchment, wastewater treatment plants (WWTPs)

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INTRODUCTION

The inlet works, primary sedimentation tanks (PSTs), thickening, biosolids dewatering and biosolids storage locations at wastewater treatment plants (WWTPs) have all been identified as locations of intense odour emissions (Frechen 1988; Dincer & Muezzinoglu 2008; Ras *et al.* 2008; Zarra *et al.* 2008; Lehtinen & Veijanen 2011). Onsite odour emissions from the inlet works and primary sedimentation can be controlled by chemical dosing, frequent desludging and the installation of odour abatement systems (Gostelow *et al.* 2001). However, emissions from the biosolids produced at the WWTPs can be harder to mitigate and, if left untreated, can affect the community during onsite processing and storage, transportation and land applications.

Odour emissions from the treatment of wastewater are predominantly composed of volatile sulfur compounds (VSCs) (Vincent 2001). The generation and emission of these VSCs are dependent on microbial activity as well as the chemical and physical properties of the sludge. These,

in turn, are influenced by the inlet composition of the wastewater and WWTP performance. A diverse range of volatile organic compounds (VOCs) are also emitted from wastewater biosolids processing. While these compounds may be generated from the degradation of organic material, they may also originate from industrial and municipal flows into the WWTPs sewer catchments (Wang *et al.* 2012). A range of VOCs are known to contribute to malodours, yet previous studies often overlook the contribution of VOCs in comparison with VSCs (Sivret *et al.* 2016). While VOCs only contribute to a small proportion of the odour load, their presence may affect the operation of odour abatement systems, e.g. high levels of ketones adsorb to activated carbon and reduce the adsorption of competing odorants or prematurely deplete the carbon (US EPA 1988). In addition, the remaining VOC levels, if left untreated in favour of VSC removal in odour abatement systems, may contribute to onsite nuisance emissions. This is especially important in the case of spikes of VOCs entering

the WWTPs due to the extremely variable and unpredictable flows into the sewer catchments due to industrial flows.

METHODOLOGY

Site descriptions

Emissions generated from sludge sampled throughout the biosolids processing of five WWTPs were analysed in this study. As shown in Table 1, the sites varied in scale,

treatment level, and types of flows entering the sewer catchments. The number and types of industries recorded to discharge into the sewer catchments of each site was analysed from tradewaste data supplied by the utility. The sites also varied in terms of the types of odour abatement systems used onsite (Table 1).

Sampling methodology and emission analysis

Samples of sludge were taken throughout the biosolids processing trains of five WWTPs (A–E). Emissions from the

Table 1 | Site description of the biosolids processing configuration at the five WWTPs (A–E)

	A	B	C	D	E
Influent (ML/yr)	110,000	19,000	13,000	5,000	16,000
Catchment description	Large catchment, >200 registered trade waste emitting sites	>20 trade waste emitting sites	>25 trade waste emitting sites	No registered trade waste emitting sites	>30 trade waste emitting sites
Inlet and primary treatment	Rotary drum screens, grit tanks, high rate PSTs	Step screens, aerated grit, PSTs	Step screens, aerated/vortex grit chambers, PSTs	Step screens, aerated/vortex grit chambers, PSTs	Step screens, grit tank, PSTs
Secondary treatment	None	Activated sludge using Modified Ludzack–Ettinger (MLE) configuration	Conventional activated sludge with anoxic zones for partial nitrogen removal	Conventional activated sludge	Biological nutrient removal using BIODENIPHO™ process configuration, Parallel to conventional activated sludge
Sludge thickening	Rotary drum	Gravity thickeners for primary sludge, DAF for WAS	Centrifuge for WAS	Centrifuge for WAS	Gravity thickeners for primary sludge, Centrifuge for WAS
Anaerobic digestion SRT	19 days	12 days	20 days	32 days	19 days
Dewatering method	High solids centrifuge	Low solids centrifuge	High solids centrifuge	Low solids centrifuge	High solids centrifuge
No. of sludge and centrate sampling locations	7 locations	7 locations	6 locations	6 locations	6 locations
Installed odour control devices	Wet chemical scrubber for inlet works associated foul air Biotrickling filter for biosolids related foul air	Biotrickling filter followed by activated carbon system for inlet works, primary sedimentation and sludge thickening associated foul air Biofilter treating foul air from biosolids dewatering	Biofilter treating foul air from the inlet works Biofilter and wet chemical scrubber treating foul air from grit removal and PSTs Wet chemical scrubber also treated air from the biosolids storage shed	Biofilter treating foul air from the inlet works and PST emissions	Wet chemical scrubber treating foul air from the inlet works, PSTs, thickeners and biosolids shed

Note: primary sedimentation tanks (PSTs), solids retention time (SRT), dissolved air flotation (DAF), waste activated sludge (WAS).

sludge samples were generated using a dynamic flux hood according to AS/NZS 4323.4:2009 from [Standards Australia/Standards New Zealand \(2009\)](#), carried out at ambient conditions (20–25 °C). Emission sampling was conducted within 6 h of biosolids collection. The emissions generated using the dynamic flux hood method represent potential emissions from the sludge, rather than actual *in situ* measurements.

Emission samples were collected in Nalophan sample bags for the analysis of VSCs. The sample bags were connected to an Air Server (CIA 8, Markes International, UK) and emissions were pre-concentrated onto a specialised sulfur cold trap (U-T6SUL, Markes International, UK). The samples were desorbed from the cold trap into a gas chromatograph (GC) (7890N GC, Agilent Technologies, USA) then to a sulfur chemiluminescence detector (SCD) (355 Sulphur Chemiluminescence Detector, Agilent Technologies, USA). A DB-VRX (30 m × 0.25 mm × 1.4 µm) column (Agilent Technologies, USA) was utilised in the GC for compound separation. Operational parameters of the TD-GC-SCD are described in [Wang *et al.* \(2015\)](#). H₂S was analysed directly from the Nalophan bags using a portable analyser (Jerome 631X, Arizona Instruments, USA).

VOCs were measured by capturing emissions from the flux hood on Tenax-TA sorbent tubes adsorbed using a vacuum sampling pump (Air-Chek2000, SKM Inc.). Sorbent tubes were analysed using a GC equipped with a mass spectrometer (MS) detector (Agilent 6890N GC, 5973NS MS, Agilent Technologies, USA). The gas chromatography column used was DB-VRX (30 m × 0.25 mm × 1.4 µm). Sorbent tubes were loaded with an Ultra automatic sampler and thermally desorbed using a Unity thermal desorber (TD) (both from Markes International, UK). The emission samples were concentrated onto a general purpose cold trap (Markes International, UK) prior to injection to the GC. Operating conditions used in the TD-GC-MS system are detailed in [Wang *et al.* \(2012\)](#).

Data analysis

VOCs were identified by matching the identity of peaks in the MS spectra with NIST11 fragment library. The identified peaks were then semi-quantified against toluene as a reference compound. Standard curves were prepared on the TenaxTA sorbent tubes and analysed together with each sample batch to account for instrument variations. More information on semi-quantification approach taken to identify VOCs is described in [Fisher *et al.* \(2017\)](#).

VSC peaks on the SCD were quantified by comparing the retention time to a set of 16 liquid and gaseous sulfur standard compounds, and concentrations were calculated based on SCD peak area and standard curves for each sulfur standard ([Wang *et al.* 2015](#)).

The odour detection thresholds (ODTs) of the identified odorants were used to standardise the odorant concentrations in terms of their sensorial importance using Odour Activity Values (OAVs) as calculated using Equation (1). ODTs were sourced from [Nagata \(2003\)](#) when available, the full list of odorants and their ODTs can be found in [Fisher *et al.* \(2017\)](#) and [Fisher *et al.* \(2018\)](#).

Odour Activity Value (OAV)

$$= \frac{\text{Odorant Concentration}}{\text{Odour Detection Threshold (ODT)}} \quad (1)$$

RESULTS

Emission trends throughout biosolids processing

The majority of the odorous emissions from sludge throughout biosolids processing were sulfur based in terms of both overall concentration and sensorial importance, evaluated by OAVs ([Figures 1 and 2](#), respectively). The dominant sulfur compounds were hydrogen sulfide, methyl mercaptan and a range of other VSCs such as dimethyl sulfide. This is similar to the key odorants identified in sewer systems ([Sivret *et al.* 2016](#)).

The comparative load of VOCs in emissions was the highest from dewatered sludge (DWS), particularly at Sites A and C, which had comparatively low VSC emissions. VOC concentrations at the primary sludge and inlet area had a comparatively lower proportion (<1%) of the total emission concentrations. However, due to the variability in the inlet of the plant, spikes of volatile substances from the sewer catchment may be emitted periodically. If these are not removed, volatilisation in turbulent sewers could cause high concentrations to potentially enter odour abatement systems at the WWTPs. Between the WWTPs, the load of VOCs emitted, mostly from the DWS and stored sludge, were roughly comparable to the number of registered trade waste emitting sites in the upstream catchment shown in [Table 1](#). The highest concentrations of VOCs emitted were the ketones, butanone and acetone, and the aromatics, toluene and

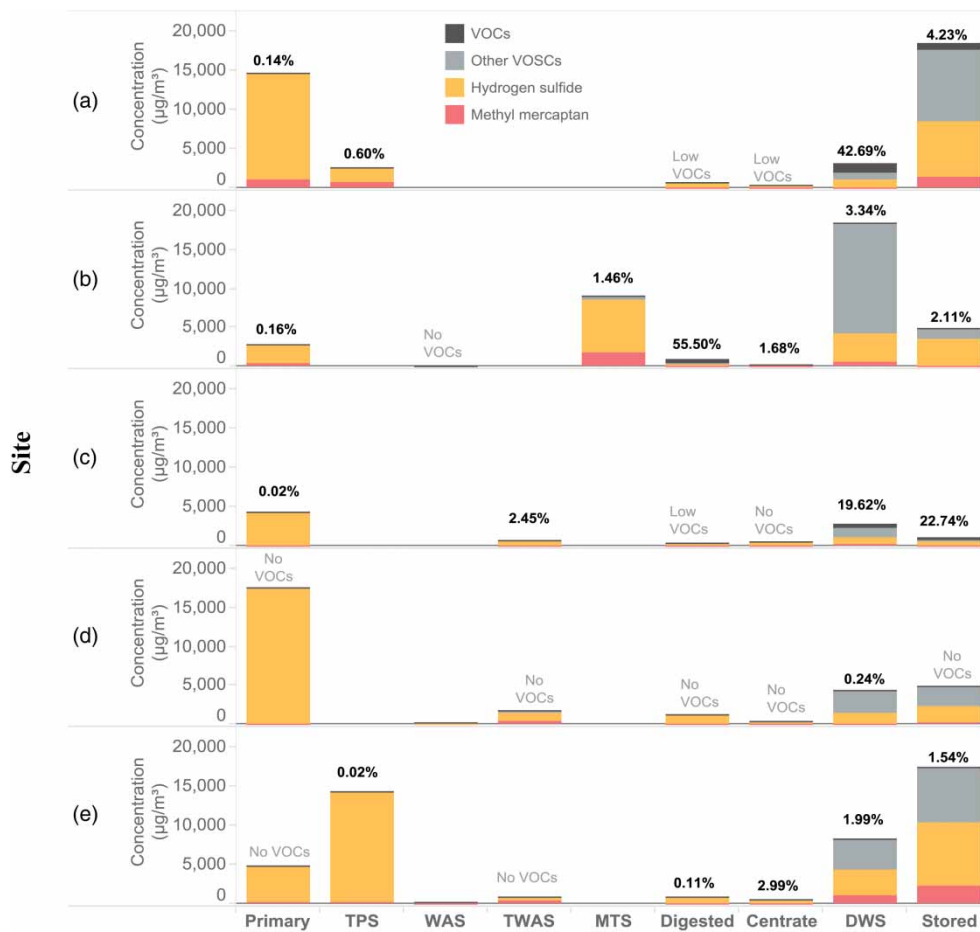


Figure 1 | Odorant emissions throughout the biosolids processing of five WWTPs evaluated both by concentrations of total VSCs compared to VOCs $\mu\text{g}/\text{m}^3$. The percent VOCs contribute to the overall emission concentrations are shown in the text above each column. It is also noted when the average VOC concentration was $<1 \mu\text{g}/\text{m}^3$ as low VOCs, suggesting levels are close to analytical detection thresholds or infrequently detected. PS = primary sludge; TPS = thickened primary sludge; DWS = dewatered sludge; MTS = mixed thickened sludge at Site B; WAS = waste activated sludge; TWAS = thickened WAS.

trimethyl benzene. A range of terpenes and halogenated compounds were detected at site A, while site B emitted a variety of cyclic alkane compounds at much greater concentrations than the other sites.

DISCUSSION

Compound origins

VSCs may be produced from the degradation of sulfur containing proteins making up the organic matter, while hydrogen sulfide is also produced from the reduction of sulfate. Emissions from inlet works and PSTs typically have higher ratios of VSCs to VOCs. This is due to the high levels of hydrogen sulfide emissions (primarily due to the reduction of sulfate to sulfide ions), as well as the lower

rates of VOC volatilisation due to their adsorption to the solid organic fraction of the wastewater for the larger hydrophobic compounds (Hudson & Ayoko 2008).

The origin of odorants such as halogenated, alkanes, cycloalkanes, aromatics and terpenes is likely from anthropogenic sources such as industrial or household flows into the sewer catchment (Wilson *et al.* 1994; Dincer & Muezzinoglu 2008; Kotowska *et al.* 2012). The detection of these compounds in emissions throughout biosolids processing confirms that they are not wholly removed by biological degradation in the stabilisation process. Therefore, their levels in the biosolids are affected both by the inputs to the upstream sewer catchment, but also to the onsite treatment at the WWTPs. The presence of a refinery in the sewer catchment area of Site B is the likely source of the high levels of cycloalkanes, unique to that site. While little is known of their odour properties, based on their ringed

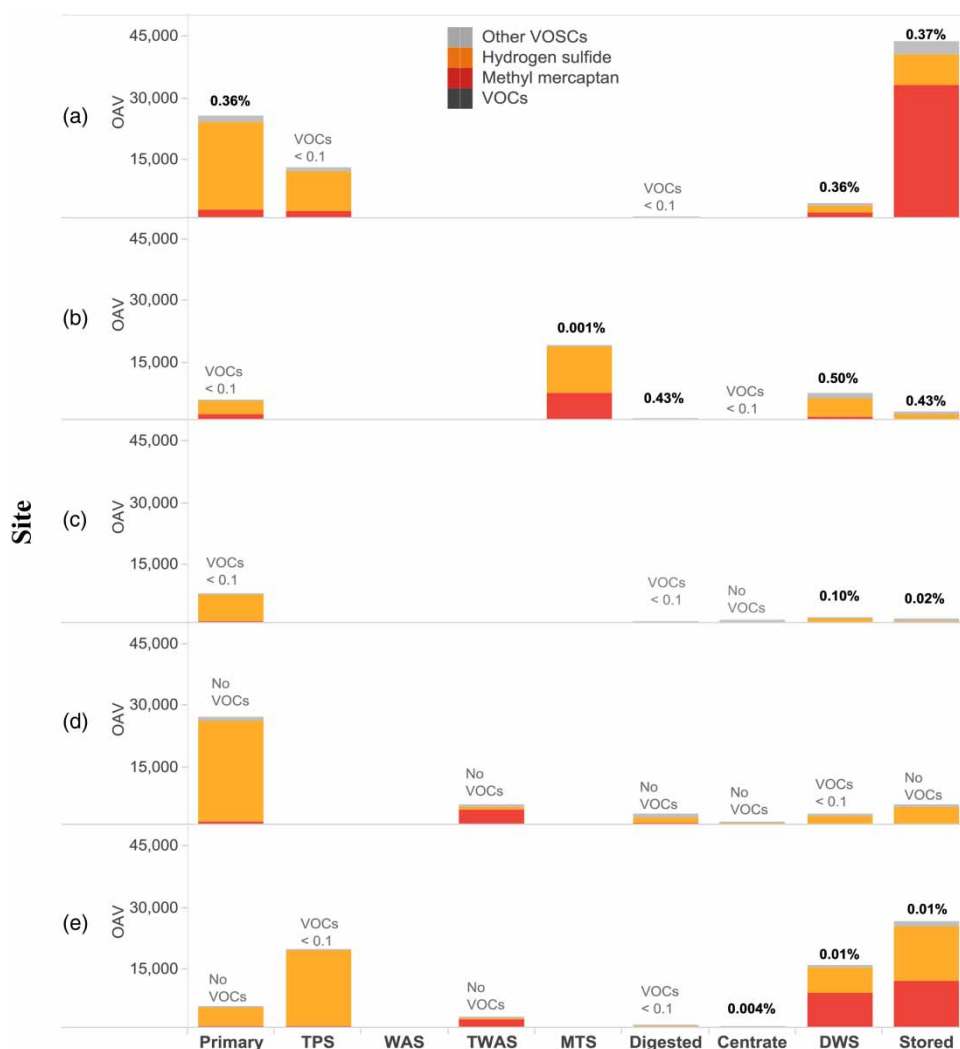


Figure 2 | Comparison of the sensorial importance of hydrogen sulfide, methyl mercaptan, other VOSCs and VOC odorants based on average odour activity values (OAVs) for each sampling location in the WWTPs. The percent the total OAV that the VOCs contribute are shown in the text above each column. VOCs < 0.1 indicates when the average OAV for VOCs was less than 0.1, suggesting VOCs are not likely to be perceptible. PS = primary sludge; TPS = thickened primary sludge; DWS = dewatered sludge; MTS = mixed thickened sludge at Site B; WAS = waste activated sludge; TWAS = thickened WAS.

structure, they are unlikely to be easily degraded in biological processes.

The degradation of proteins is also the likely source of other odorants such as the aromatic indole, *p*-cresol and ethylbenzene and toluene. However, some aromatics detected such as styrene, xylene and trimethyl benzene isomers are likely present due to industrial emissions. According to the observed OAVs, these compounds have the potential to be perceived onsite, however, are likely overpowered by the VSC emissions prior to odour abatement.

Other compounds detected in emissions, not thought to be a product of organic degradation were ketones such as methyl ethyl ketone, the terpenes limonene and pinene (likely from household cleaning products (Wang *et al.*

2012)) and a variety of alkanes both straight and cyclic. Some aromatic and terpene compounds were detected from Site A, at similar concentrations to their ODTs. Meaning community may be able to detect them very close to the source, however, unless large concentrations are released, dispersion will dilute such concentrations to subthreshold levels before they reach potential complainants.

When considering the large number of industrial sites emitting into the sewer catchment of Site B, the range of VOCs emitted from the dewatered biosolids (Figure 1) is unsurprising. While concentrations in the plant inlet are likely low, the VOCs are likely concentrated by adsorption to organic matter in the biosolids. Similar effects are expected with loads of heavy metals to the site. This requires

the total load of pollutants, rather than concentrations entering the site, to be considered.

Odour management consequences

Compared to emissions of sulfur based compounds, from the locations and plants sampled, the detected industrially originating compounds are unlikely to be dominant odorants in normal conditions. Yet, such compounds can affect the performance of odour abatement systems. In activated carbon systems, these compounds can be adsorbed and then released at a later time, such that the outlet concentration is greater than the inlet concentration (Shammy *et al.* 2016). The presence of VOCs at concentration below the odour threshold can prematurely saturate some activated carbon and reduce the useful life of the odour abatement system (Kyi 2014; Mohamed *et al.* 2014). VOCs are removed to a lesser degree than VSCs in biological systems with hydrophobic substances and halogenated compounds suffering poor removals (Delhoménie & Heitz 2005; Iranpour *et al.* 2005; Kennes *et al.* 2009; Shammy *et al.* 2016). This could lead to odour being dominated by VOCs, rather than VSCs, in treated air. In wet chemical scrubbers, the intermittent presence of some VOCs can increase the chemical requirements and adversely affect the control system such that other odorants are not as effectively removed (Davidson 2002). If the wet chemical scrubbers are designed to treat the intermittent increased VOC load, the contact requirements can increase significantly leading to larger and more costly scrubbers (Hentz & Balchunas 2000).

Emissions from the primary sludge, while dominated by H₂S with a low sometimes negligible VOC load may be affected by spikes of high volatility compounds from the sewer catchment. Therefore, odour abatement systems should be able to cope with these sporadic events. The wet chemical scrubbers installed at the inlet works of Site A would control any sporadic events, however, potentially have large chemical requirements. While Site B had less industrial emitters in its catchment the combination of a bio-trickling filter and activated carbon may be affected by high sporadic levels of VOCs emitted.

As high levels of VOCs relative to VSCs were present in emissions from the dewatered and stored biosolids, particularly at sites with more industrial catchments, odour abatement systems should be chosen that can perform well with the presence of these compounds. The use of biological systems as seen at Sites A and B may be affected by the

remaining VOCs in emissions from these locations once the VSCs are removed.

CONCLUSIONS

While VSCs are the predominate odorants emitted throughout wastewater treatment, the presence of VOCs, which are largely unmonitored in emissions, may reduce the efficiency of odour control devices or in some cases also contribute to the odour emissions. The ratios of VSCs to VOCs in emissions vary throughout biosolids processing at the five WWTP sites monitored. This ratio is dependent on the upstream catchment, which influences the types of VOCs present, and the treatment stage that influences their formation and emission. Odour management strategies should consider the overall emissions both before and after odour abatement, not just dominant odorants.

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