

## Water Environment Research Foundation (WERF) anaerobic digestion and related processes, odour and health effects study

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**Abstract** Biosolids odour emissions can affect the ability of wastewater utilities to implement beneficial biosolids processing and reuse programs. Communities often become more sensitised and vocal about biosolids issues, once they experience odours emanating from a nearby site. Odour impacts from biosolids, including potential human health effects, have been targeted recently by many national and local newspapers, citizens' groups, and regulatory agencies, who have raised significant concerns, ranging from viable disposal methods/sites to outright bans. Many national and local regulatory agencies in the United States are considering biosolids disposal bans in their communities because of misinformation, poor science, and citizen pressure, but primarily because of odour impact concerns. The wastewater industry has a relatively poor understanding of the operations and treatment parameters that influence biosolids odour emissions. Thus, wastewater treatment plants are often unable to control the odour quality of the biosolids that are delivered into communities. A research study to demonstrate the influence of anaerobic digestion, mechanical dewatering, and storage design and operating parameters on the odour quality of the final product was performed and is the subject of this paper. Established and new sampling and analytical methods were used to measure biosolids odour emissions from 11 test sites in North America. By determining the impacts of these control variables on biosolids odour quality, design and operations of anaerobic digestion systems might be enhanced. This paper also summarises a corollary study performed as part of the WERF research study that addresses the health effects of biosolids odours.

**Keywords** Anaerobic digestion; biosolids; health effects; odours; wastewater; WWTP

### Introduction

Biosolids odour emissions from wastewater treatment plants (WWTPs) constitute the number one issue that most Water Environment Research Foundation (WERF) member agencies cite for problems with biosolids disposal in their communities. WWTPs are often unable to control the odour quality of the biosolids that are delivered into communities, because the wastewater industry in general may have a relatively poor understanding of the operations and treatment parameters that influence biosolids odour emissions. As communities become more sensitised and vocal about biosolids odours emanating from

and experienced by the communities, many national and local newspapers, citizens' groups, and regulatory agencies are beginning to target odour impacts from biosolids, including potential human health effects.

A WERF-funded project (Project 00-HHE-5 – Identifying and Controlling the Municipal Wastewater Environment), that has been under way since February 2000, seeks to identify and explore gaps in knowledge concerning odour generation in the wastewater treatment industry. The project to date has comprised a comprehensive review of published and unpublished literature related to identification and control of odours associated with municipal wastewater collection systems, wastewater treatment processes, and biosolids processing facilities (Phase 1), and a full-scale, comparative field and laboratory study of odour parameters related to biosolids processing (Phase 2). The goal of the Phase 2 study is to determine the impact of the design and operation of biosolids processing (storage, anaerobic digestion, and mechanical dewatering) on the odour quality of the final product. The WERF project also included a health effects literature study to determine whether odours from biosolids cause illness.

This paper provides general information on the 11 WWTPs in North America that were tested as part of the Phase 2 study; a description of the sampling and analytical approaches used to measure biosolids odour emissions at these plants; a discussion of the results obtained; and also a summary of the literature study on the health effects of biosolids odours.

## Methods

A testing and sampling protocol was developed to encompass plant system-operating parameters monitored at sampling points throughout the process. This protocol for sampling locations was customised for each participating WWTP. Since each plant had a number of unique operational points, the protocol was modified to allow samples to be representative and comprehensive of the processes both upstream and downstream of the anaerobic digestion process.

### Participating WWTPs

Ten of the WWTPs tested were located in United States, and one was located in Canada. These test facilities spanned a wide range of plant sizes, from the smallest WWTP, receiving 49.2 million litres per day (mld) of influent flow, to the largest WWTP operating at 1,325 mld. Table 1 lists some of the information gathered from these plants, including wastewater treatment process, anaerobic digestion, and biosolids processing. These WWTPs received predominantly domestic wastewater flows, with varied mixes of industrial contributions, which is typical of large urban areas. All of the WWTPs employed anaerobic digestion, with 10 of the digestion systems operating in the mesophilic temperature range, and one operating in the thermophilic temperature range. The WWTPs employed various technologies for biosolids thickening, dewatering, conveyance of dewatered cake, and end use or disposal.

### Sampling procedures

Figure 1 identifies the generic sampling locations (A through I) within a WWTP biosolids process train that were analysed as part of this study. Corresponding sampling locations at each participating WWTP were identified and locations added or subtracted specific to their particular process schemes. In addition to these sample locations, a 24-hour composite sample of the influent to each WWTP was taken.

Samples were collected before and after each of the biosolids treatment processes and analysed for constituents in the liquid, solids, and gas headspace phases of each sample.

**Table 1** Summary of information gathered from participating WWTPs

Plant flow (m <sup>3</sup> /d)	CAS or HPO	Domestic wastewater contribution (%)	WAS thickening	Digestion type	Digestion SRT (day)	Dewatering type	Chemical addition locations		Biosolids conveyor type
							Iron	Polymer	
WWTP No. 1	136	HPO	100	DAFT	Mesophilic	38	Low-solids centrifuges	DAFT, dewatering	Screw, belt, hopper, truck
WWTP No. 2	757	HPO	90	DAFT	Mesophilic	20	Low- and high-solids centrifuges		Screw, belt, truck
WWTP No. 3	257	HPO	90	DAFT	Mesophilic	27	Low-solids centrifuges	DAFT, dewatering	Belt, silo
WWTP No. 4	114	CAS	60	Belt	Mesophilic	40	Lagoons	Grit channel	Belt, secondary clarifiers
WWTP No. 5	76	CAS	90	Belt	Mesophilic	27	High-solids centrifuges	Aeration effluent	Hopper, truck
WWTP No. 6	227		90	Gravity thickener	Mesophilic	28	Low-solids centrifuges	Belt, dewatering	Cake pump, pad
WWTP No. 7	64	CAS	95	Gravity thickener	Mesophilic	14	Low-solids centrifuges and drying beds	Dewatering	Belt
WWTP No. 8	1,325	HPO	85	Centrifuge	Thermophilic	16	High-solids centrifuges	Primary effluent	Cake pump, silo, truck
WWTP No. 9	49	CAS	91	DAFT	Mesophilic	21	Plate and frame	Communitor	Gravity into truck
WWTP No. 10	1,325	HPO	80	DAFT	Mesophilic	19	Low-solids centrifuges	Grit removal, secondary clarifiers, DAFT plate and frame	
WWTP No. 11	757	CAS	93	DAFT	Mesophilic	22	High-solids centrifuges	Primary sludge Pre-primary DAFT	Belt High-pressure pump

HPO = high-purity oxygen

CAS = conventional activated sludge

DAFT = dissolved air flotation

SRT = solids residence time

WAS = waste-activated sludge

Sample collection and analysis at each of the 11 WWTPs occurred from May through October 2002.

The bottle–headspace method of sampling was used to simulate the odours from samples stored in bunkers, hoppers, or trucks and bound for land application or disposal. This method of sampling is capable of eliminating the changing conditions of emission flux, atmospheric dilution and oxygen that are typically associated with using air sampling, flux chamber, and purge-and-trap sampling methods. While it is recognised that the bottle–headspace sampling method may not represent actual field conditions, the consistent sampling and analytical protocols that were used for all 11 WWTPs in the study resulted in a useful and statistically valid comparison of analytical results from the large number of samples collected.

#### Analytical procedures

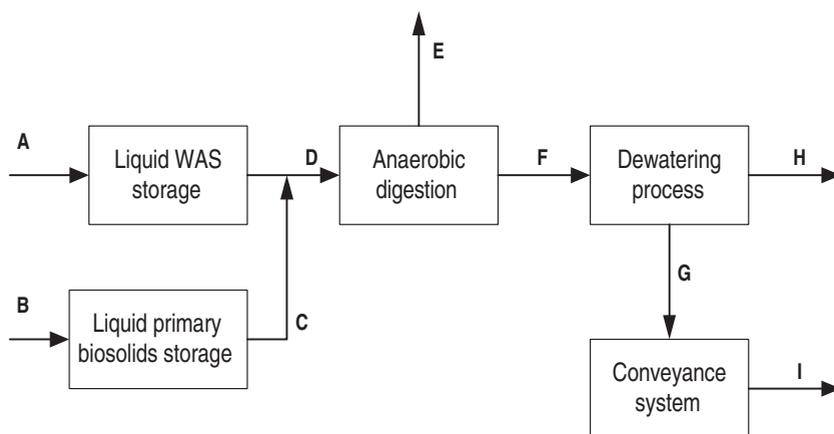
Samples collected were analysed for measurable chemical and odour quality parameters, using Standard Methods (APHA, 1998). These included field analyses; headspace analyses (chemical and olfactometry); organic compounds analyses; protein, enzyme, and acid analyses; cations and anions analyses; and residual biological activity analyses.

Liquid and cake samples were analysed for volatile solids (VS), total solids (TS), temperature, pH, oxidation–reduction potential (ORP), sulfides, alkalinity, soluble total-Kjeldahl nitrogen (TKN), and faecal coliform bacteria according to Standard Methods (APHA, 1998) procedures.

Hydrogen sulphide ( $H_2S$ ) gas concentrations in the headspace of the digester gas were measured in the field using colorimetric tubes. The  $H_2S$  concentrations at all other locations were measured using a Jerome  $H_2S$  analyser. Ammonia ( $NH_3$ ) concentrations in the field were measured using colorimetric tubes.

Headspace odour samples were analysed with gas chromatograph/mass spectrophotometer (GC/MS) to estimate differences in odour emissions of different biosolids over 49 days. Compounds measured included  $H_2S$ , methane thiol, dimethyl sulphide (DMS), dimethyl disulphide (DMDS), dimethyl trisulphide, carbonyl sulphide (COS), carbon disulphide ( $CS_2$ ), carbon tetrachloride, isopropyl mercaptan, *tert*-butyl mercaptan, *n*-propyl mercaptan, ethyl methyl sulphide, trimethyl amine (TMA), acetone, indole, and skatole. Headspace odour samples were also used with olfactory odour analysis in accordance with ASTM standard practices to determine odour detection thresholds (DT) and recognition thresholds (RT) and to profile odour using descriptors.

Liquid-phase analyses of organic compounds performed on the samples collected



**Figure 1** Generalised test facility flow schematic with sample locations

included the measurement of proteins, amino acids, enzyme activity, and volatile fatty acids (VFAs). For each of these organic compounds, the analysis was further divided into fractions, which included soluble, bound or labile, and total organic constituents.

Cations and anions were measured in the liquid phase of the samples and, like the organic compounds analyses, were divided into fractions, including soluble, bound or labile, and total amounts of the various constituents.

Additional VS destruction, methane, and  $\text{NH}_3$  production data for liquid or cake samples were determined in order to determine residual biological activity (RBA). VS destruction was evaluated using the Van Kleeck formula. Methane and  $\text{CO}_2$  concentrations were measured using a GC thermal conductivity detector. Analysis of ammonium ions was performed using an ion-chromatograph DX-300 from DIONEX.

## Results and discussion

Analytical results and WWTP data were evaluated using several statistical analysis techniques to examine the numerous relationships between analytical parameters and process data and to evaluate potential correlation between plant parameters and biosolids odour generation, as described below.

### Odorous compounds in biosolids

Odorous compounds in biosolids include volatile sulphur compounds (VSCs), TMA, indole and skatole, and VFA. VSCs include  $\text{H}_2\text{S}$ , methane thiol or methyl mercaptan (MT), DMS, DMDS, COS, and  $\text{CS}_2$ . The study shows that odour from biosolids (a subjective human perception) can be quantified by olfactometry and correlated with the concentrations of some of the odorous chemical compounds in biosolids. Specifically, chemical and olfactory odour analyses revealed that odours from biosolids correlate well with VSC concentration in the sample headspace. There is also a positive correlation between odour DT and volatile MT. There is, however, no discernible relationship between odour DT and peak volatile nitrogen (TMA, indole, skatole) and between odour DT and VFA concentrations.

### Water constituents impacting biosolids odours

Results of the study show that protein and, more specifically, the sulphur-containing amino acids that make up the protein, are the main precursors for VSC production from stored cake samples. However, the study shows that protein-degrading enzyme activity measured in cake and digester samples does not necessarily correlate well with subsequent odour production from stored cake. In addition, protein-degrading enzyme activity does not appear to be a good predictor of digester performance, as it does not correlate well with digester performance parameters such as SRT, VS destruction, or loading rates. Therefore, protein-degrading enzyme activity should not be used as a tool for measuring the odour potential of a dewatered biosolids sample.

It could not be shown, based on the study results, that cation concentration of the influent wastewater affects the odour production of dewatered biosolids. However, a relationship between cation content and protein concentration is suggested, indicating that cations such as iron likely play some role in affecting the bioavailable protein for VSC associated with odour production.

### Influence of WWTP operations on biosolids odour

WWTP process operating parameters were reviewed in search of relationships between process parameters and biosolids odours. Data from the study showed that mixing primary sludge and waste-activated sludge (WAS) can increase odours from liquid biosolids before

and after digestion. The data do not show that WAS has a higher potential than primary sludge for odour generation. Data from the study also showed that neither primary sludge detention time nor WAS solids retention time (SRT) appeared to have any significant relationship with biosolids odours.

The impact of digestion on biosolids odour generation was reviewed. While it is generally believed that efficient anaerobic digestion and stabilisation of biosolids in accordance with the US Environmental Protection Agency Part 503 regulations should also lead to a reduction of odours in digested biosolids, the study did not show that anaerobic digestion (with 38% VS destruction) reduces odour production from dewatered biosolids. Attempts to correlate conventional biosolids stability criteria (VS destruction, RBA, and digester effluent acetic acid concentrations) with dewatered cake odour DT or peak organosulphur emissions did not reveal any conclusive results. In addition, there was very little correlation between digester SRT and dewatered cake odour DT. The study indicated that thermophilic digestion may lead to different biosolids odours compared to mesophilic digestion (based on data from one of the WWTPs that utilised thermophilic anaerobic digestion) and that more research is necessary to better understand the odour characteristics of thermophilically digested biosolids.

It was found that post-digestion processing and handling of anaerobically digested biosolids can increase odour generation in dewatered biosolids. A side-by-side evaluation of a high-solids centrifuge and a low-solids centrifuge at one of the plants in the study indicated that high-solids centrifuges can have a greater impact on the release of bioavailable protein from biosolids, and hence produce more VSCs than low-solids centrifuges. The evaluation shows that a 30 percent increase in dewatered cake solids resulted in an over 120% increase in total peak sulphur production and a 240% increase in odour DT. The impacts of cake conveyance devices on odour or VSC production could not be ascertained, particularly because some of the samples obtained for the study were from storage silos that were not immediately downstream of the conveyance equipment.

#### **Health effects of biosolids odours**

The health effects of biosolids odours study started with the review of a 340-article bibliography in the *Journal of Agromedicine*, on odour emissions from various biosolids generation sources. This review found virtually no published records on odour and illness from WWTP-related biosolids, implying that odours as sensations, whether from the biosolids of publicly owned treatment works (POTWs) or from other industrial operations, might not in fact cause illness at concentrations below known toxic levels.

Anecdotal reports nevertheless imply a pattern much like that associated with other industrial malodours. Any connection between odour and illness has received little note among the millions of articles in the medical literature. This state of affairs presumably exists because odours *per se* generate no objective signs of illness, even when people claim symptoms. Symptoms from malodours fail, on other grounds, to qualify as illness.

Symptoms claimed in connection to odours from biosolids in particular come from olfactory rather than chemoesthetic (irritating) stimulation, a conclusion derived from calculations that concentrations of emissions of the notable contaminants from WWTPs fail to reach irritating levels even within the grounds of the facilities. Although not inappropriate to the experience of malodours, symptoms seem to occur via intermediate variables such as annoyance, anxiety, and frustration. Persons who experience no such distress experience no symptoms.

Acknowledgement that odours cause anxiety and the like should inform strategies for how to deal with reports of symptoms. Research into the connection between the composition of the emissions from WWTPs and odour character should seek to illuminate

quantitative goals that engineers can seek to achieve. Finally, failure to respect the boundary between the subjective and the objective in discussions of the matter can invite flatly incorrect conclusions about the relationship between odours and illness.

No one can deny that WWTPs may produce unacceptable odours, even when their emissions fall below levels set to protect public health. The literature gives no encouragement that these unacceptable odours cause illness. In particular, (1) odours as sensations do not cause signs of illness; (2) the acceptability–unacceptability of odours varies systematically and predictably with circumstances of exposure, and depends on the *meaning* associated with the exposure; (3) below toxic levels of exposure, symptoms associated with odours involve no pathology; (4) removal of the source of odour will result in immediate reduction of symptoms; and (5) non-physical variables such as anxiety seem to mediate symptoms from odours. WWTPs could take the fifth point to heart, both for the responsibility that it implies and for the opportunity that it may present for understanding the expression of symptoms. Nothing will reduce symptoms better than control of emissions. WWTPs should of course seek to produce as little annoyance or anxiety as possible, but should also recognise the mediating states as the source of symptoms.

Finally, research on the sensory consequences of WWTPs could profit from approaches taken in the sensory analysis of foods, where odour quality receives as much attention as odour intensity and potency. Study of the “sensory anatomy” of odours from WWTPs might sharpen targets for control and thereby give the engineer greater leverage to minimise annoyance.

## Conclusions

With respect to all of the parameters analysed in this study, available protein was confirmed to be the main contributor to the odour potential of biosolids. During the endogenous growth of bacteria that takes place in the anaerobic digesters, proteins are broken down into amino acids that are consumed as substrate by specialised microbial groups. These degradation reactions release the sulphur- and nitrogen-bearing volatile organic compounds as end products, and those end products are the main source of odours associated with biosolids. Recognising that this study finds a clear and conclusive relationship between bioavailable protein and biosolids odour production, it follows that destroying more releasable proteins during digestion will result in lower odour production from biosolids cake. It is therefore apparent that processes capable of enhancing digestion to destroy higher amounts of VS and bioavailable protein will result in lower odour emissions from biosolids cake. The project team concludes that a variety of predigestion processes, such as pasteurisation, digestion chemical treatment, thermal processing, two-phase digestion, thermophilic anaerobic digestion, mesophilic aeration, and mechanical cell-lysing techniques should be investigated for the enhancement of digestion efficiency.

The study findings also indicate that the anaerobic digestion process is not well understood with respect to its impact on odours from digested biosolids, especially odours in biosolids cake after dewatering. There is no conclusive evidence from this study that more effective anaerobic digestion, leading to more complete digestion of complex organics, can result in lower odours in digested, dewatered biosolids cake. It appears that efficient digestion alone is not sufficient to maintain low odours when the upstream conditions or downstream processing equipment impose conditions that increase the potential for odour generation. The study recommends using controlled mechanistic studies, which provide the capability to vary one input parameter to determine its cause and effect, to investigate further the impacts of mesophilic and thermophilic digestion on downstream biosolids odours.

The health effects on biosolids odours study concludes that there is no evidence to

suggest that WWTP biosolids odour causes illness, because odours as sensations do not cause signs of illness. In addition, the degree of acceptability of odours varies depending on ingredients, their proportions, context, and generically the meaning that people attach to the sensations. Non-physical variables such as annoyance seem to mediate symptoms from odours (i.e. people report somatic effects only to the degree that they are annoyed). Also, comparison of the maximum concentrations measured at WWTPs and estimates of chemaesthetic thresholds indicated that WWTPs do not evoke sensory irritation.

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