High-solids centrifuge is a boon and a curse for managing anaerobically digested biosolids

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Abstract High-solids centrifugation can reduce the cost of managing or disposing of anaerobically digested biosolids. High-solids centrifuges can increase relative cake solids by as much as 5% DS compared with other dewatering devices, such as belt filter presses, with a resulting 15–20% reduction in overall mass of hauled biosolids. Cost reductions can be similar (15–20%) or more, depending on the type of disposal or management involved. For example, the additional removal of water from the cake increases the energy content in the biosolids, thereby facilitating incineration or heat drying processes. For land application, the benefits are more mixed. As explained in this paper, increases in biosolids odours associated with high-solids centrifuges may increase digestion requirements and may compel producers to transport biosolids to more remote, distant sites, potentially increasing transportation costs. High-solids centrifuges shear anaerobically digested biosolids. The shear results in a net increase in labile protein, an odour precursor. Additionally, high-solids centrifugation also results in the inhibition of methanogenesis, a major mechanism for degradation of organosulphur odours. Therefore, the risks and benefits should both be weighed when considering high-solids centrifuges for land application of anaerobically digested biosolids.
Keywords Centrifuge; anaerobic digestion; odour; biosolids; dimethyl sulphide; methanethiol

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Introduction

Biosolids management represents a significant operating cost for plants, between one-third and one-half of overall operating cost for most plants in North America. In North America, agricultural land application is the largest venue for managing biosolids from anaerobic digestion. Plants are increasingly using high-solids centrifuges to reduce this cost. High-solids centrifuges represent a leading edge dewatering technology for processing and managing biosolids. They produce an approximately 5% increase in cake solids as compared with low silds centrifuges and belt filter presses. High-solids centrifuges have the ability to increase cake solids though an increase in bowl speed, an increase in centrifuge torque and a decrease in differential rpm between the bowl and the scroll.

Recently, it has been shown that use of high-solids centrifuges can affect biosolids product quality. Product quality issues (Higgins *et al.*, 2002a, 2003; Murthy *et al.*, 2002a,b, 2003; Hendrickson *et al.*, 2004), such as odours, pathogen regrowth and poor stability, adversely impact long-term biosolids management strategies, unit hauling cost (cost/wet tonne) and overall management cost, the very cost intended for reduction through procurement of this equipment. The procurement of centrifuges now ought to take into account such upstream and downstream process variables. These recent investigations have shown that post-processing of digested biosolids can increase odour production and emission in stored biosolids cakes. These studies have specifically shown that biosolids cakes processed using high-solids centrifuges will have a higher odorant production potential than those dewatered in low-solids centrifuge or belt filter presses.

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These researchers have indicated that there are two mains reasons for odour production, bioavailable protein degradation and inhibition of methanogenesis.

Higgins *et al.* (2003) suggested that a balance exists between protein degradation and methanogenesis. If this balance is upset, intermediate products such as methanethiol are formed and emitted from the biosolids. The protein remaining after anaerobic digestion will degrade and mineralise slowly and represent residual biological activity in the cake as long as the post-digestion storage or processing does not increase its bioavailablity (available for biodegradation). However, if protein bioavailablity increases after digestion, it can break down to form odour compounds. Protein contain amino acids with sulphur and nitrogen containing groups (e.g. cysteine, methionine and tryptophan) that can break down to form odorous volatile sulphur compounds (VSCs), such as mercaptans and dimethyl sulphide and nitrogenous compounds such as indole and skatole. For example, Pohl *et al.* (1984) have described the formation of mercaptan compounds by methionine degrading bacteria.

Similarly, Higgins *et al.* (2003) also showed that methanogens were responsible for demethylating VSCs, thereby deodorising the biosolids. Higgins *et al.* (2003) showed that chemical inhibition of methanogenesis substantially increased odorant production. They suggested that the inhibition of methanogenesis resulted in odorant production by upsetting the balance between protein degradation and methanogenesis resulting in net VSC production.

Murthy *et al.* (2002b) focused their research study on VSC production from high shear processing of anaerobically digested biosolids. They concluded that aggressive solids processing techniques such as high-shear dewatering as well as high shear conveyance could increase VSC production during anaerobic cake storage. To maximise water removal from the cakes, dewatering equipment such as centrifuges squeeze the water out of the solids. For centrifuges, this water removal process may significantly shear the biomass. The combination of conditioning and shear increases labile protein, most of which may be bioavailable. When coupled with insufficient methanogenic activity for organosulphur compound breakdown, the labile protein yields high VSC production in biosolids.

Murthy *et al.* (2002b) hypothesised that the increase in VSC production was therefore due to mobilisation of previously unavailable protein by high-shear processes, resulting in its subsequent lability or bioavailability, and degradation during storage. This lability of protein coupled with inhibition of methanogenesis results in previously non-odorous liquid-digested biosolids becoming odorous during cake storage.

The objectives of this study were to:

(1) Characterize the odorant production from anaerobically digested biosolids storage from a high-solids centrifuge.
(2) Determine the influence of dewatering equipment type on VSC production characteristics.
(3) Determine the cause of odorant production.
(4) Provide strategies for optimising anaerobically digested biosolids land application programme when using centrifuges.

Materials and methods

Approach

The approach used in this study provides a relative comparison between emissions for an experimental matrix as a means to determine the factors that control the odour potential of the biosolids material. Results may be used by researchers and operators to assist with control of odour production at the WWTP. Concentration values do not necessarily correspond to emission rates from a WWTP or ambient levels at a biosolids application site.

Overview of laboratory storage and sampling

Cake solids were collected from dewatering processes and 10 g of cake were placed in 125 mL Wheaton (160 mL headspace) serum bottles. The serum bottles were sealed using 20-mm Teflon-faced butyl rubber septa, tear-off aluminum caps and a crimping tool. All materials were purchased from Wheaton. The headspace reactor vessels were stored at room temperature for the duration of the experiments. The headspace was vented and equilibrated to atmospheric pressure prior to sampling. Headspace samples were taken from the reactor vessels using a Hamilton 1 mL gas-tight locking syringe. One millilitre of headspace was manually injected into the gas chromatograph for odorant analysis. Odorants were identified and quantified (detection limit 1 ppmv) by comparing the experimental chromatograms to those of pure standards.

Headspace analysis of odorants

For quantification of volatile organic sulphur compounds, headspace gas chromatography was performed using a Hewlett Packard 5890A gas chromatograph equipped with a flame ionization detector (FID). A Restek RT-Sulphur packed column measuring 2 m long with an inside diameter of 0.125 inches is used specifically for low-level sulphur analysis. Both the injection port and detector temperatures were held at 200 °C. Zero nitrogen was used as the carrier gas at a flow-rate of 20 mL/min. Zero air and zero hydrogen were supplied to the FID at flow rates of 450 and 20 mL/min, respectively. All gases were purchased from Airgas Inc. The duration of each sample run was 18 min. During the run, initially, the oven temperature is held at 100 °C for 3 min. It is then ramped to 220 °C at a rate of 15 °C per minute. This temperature is then maintained for 7 min, completing the run.

Labile protein extraction and quantification

The labile protein content of the cake samples was measured using a relatively mild extraction procedure. Ten grams of wet cake were suspended in a total volume of 100 mL of 50 mM phosphate buffer saline (PBS) at pH = 8.0. The suspension was mixed at 1500 rpm for 10 min and then centrifuged at 3000*g* for 15 min at 5 °C. The supernatant was filtered through a glass fibre filter with a nominal pore size of 4.2 μm. Total protein concentration of the filtrate was quantified using the RC DC Protein Assay Kit (Bio-Rad, Hercules, CA, USA) with a SpectraMax M2 microplate reader (Molecular Devices, Sunnyvale, CA, USA).

Experimental approach to determine impact of dewatering processes on VSC emission

Trials were conducted by dewatering anaerobically digested biosolids in full-scale high-solids centrifuge, full-scale low-solids centrifuge and a laboratory-scale belt filter press (BFP) simulator. The full-scale trial was conducted within a 2-h time period, to minimise variations in influent biosolids characteristics, but to allow at least 15 min time interval between runs to establish steady centrifuge operations for a change in parameter. The biosolids were obtained from a storage tank that was operated at a low-volume level with no further biosolids input from the digesters. This ensured that variations in solids characteristics were minimised to the extent that the influence of dewatering process on VSC production characteristics could be determined. The feed solids concentration at the start of the experiment was 2.19% and at the end of the experiment was 2.21% (average feed solids concentration of 2.20%). Cake samples from the dewatering runs (11 samples total) were extracted for labile protein and evaluated for odorant and methane emission. Each run represents a variation in biosolids throughput, pressure, differential rpm or polymer dose. Seven runs were performed for the high-solids centrifuge (cake solids ranging

from 26 to 34% DS) and four runs were performed for the low-solids centrifuge (cake solids ranging from 25 to 27% DS). Labile protein concentration and methane production rates were evaluated for each trial as parameters influencing odour production and mitigation. Methanethiol and DMS represented the volatile sulphur odorants.

Results and discussion

Impact of dewatering equipment type on VSC production

This study compares VSC production between centrifuges and belt filter press simulator for a single biosolids source and for similar final dry cake solids content (from dewatering equipment). Figure 1 presents the influence of dewatering equipment type on VSC emission characteristics.

The full-scale high- and low-solids centrifuges were simultaneously operated with the same polymer dose of 5.5 g/kg dry solids to obtain 26% cake solids. The laboratory-scale BFP simulator was operated at a 6.2 g/kg dry solids polymer dose to obtain 25% cake solids. Therefore, the comparisons between these experiments are for very similar polymer dose and cake solids. As shown in Figure 1, the type of dewatering equipment influenced VSC production characteristics substantially (Murthy *et al.*, 2003). The highest VSC production was obtained for the cake produced by the high-solids centrifuge. Conversely, no VSC production was detected for cakes obtained from the BFP simulator.

Murthy *et al.* (2002b) and Higgins *et al.* (2002b) have suggested that the VSC production characteristics are influenced by a combination of factors. The shearing of the biosolids cakes during centrifugation results in a release of labile protein or inhibition of methanogenesis. It appears that the BFP simulator is a low-shear device and does not increase protein lability or methanogenesis inhibition, and subsequent VSC production.

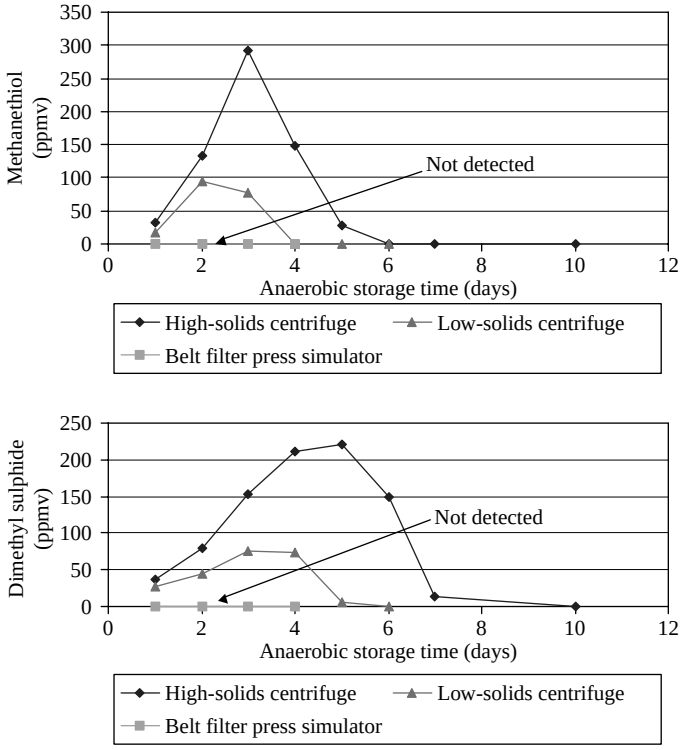

Figure 1 Influence of dewatering equipment type on VSC characteristics for similar cake solids (cake solids of 26% for centrifuges and 25% for belt filter press simulator) and polymer dose. Detection limit = 1 ppmv

It is hypothesised that irrespective of the upstream solids characteristics, low-shear dewatering and solids processing equipment will produce biosolids with low VSC production characteristics, as long as the digestion process performs adequately and a balance is maintained between protein degraders and methanogens.

Relationship between labile protein extraction and VSC emission

The factor influencing VSC production was linked to shear and protein lability. Murthy *et al.* (2002a), Higgins *et al.* (2003) and Forbes *et al.* (2003) have suggested that an increase in labile protein will increase VSC production. Murthy *et al.* (2002b) and Higgins *et al.* (2003) showed that addition of protein to biosolids resulted in an increase in VSC. Forbes *et al.* (2003) showed that the labile protein content in biosolids cakes was the single most important correlation for VSC emission when evaluating 10 mesophilic plants with anaerobic digestion. Figure 2 shows the relationship between protein lability and peak methanethiol and DMS emission for digested biosolids dewatered using high- and low-solids centrifuge (Murthy *et al.*, 2003). These data points represent several full-scale trials, 15 min apart, using the same digested biosolids source. The figure shows that a correlation exists between the extracted labile protein and peak methanethiol and DMS production. However, the scatter in the data also suggests that the initial labile protein concentration does not adequately explain VSC production and emission and that additional variables such as methanogenesis inhibition may exist. The data scatter may also mean that the measurement or calibration of protein extracts may require further refinement. For example, the degradation of protein during storage may need to be compared with VSC emission, rather than simply measuring initial labile protein concentration (since all the labile protein may not be immediately bioavailable).

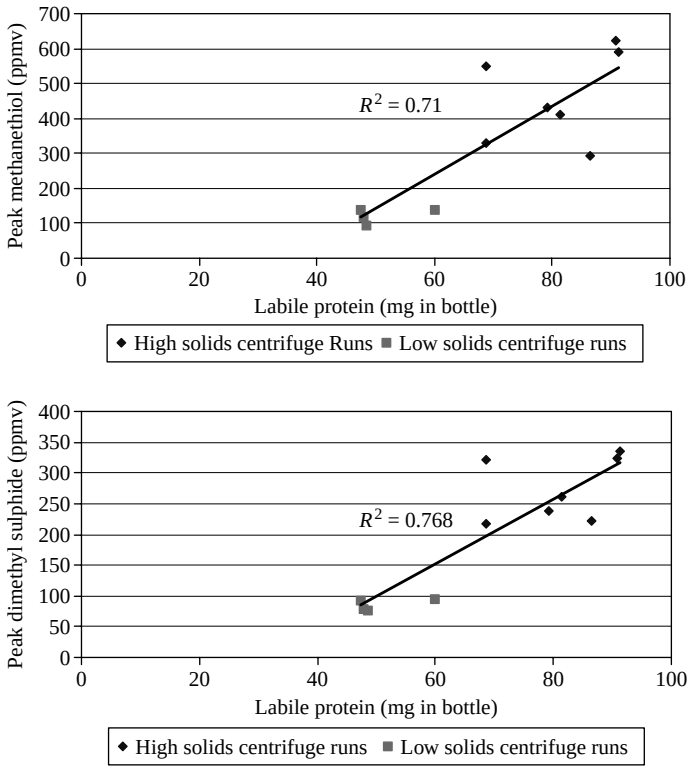

Figure 2 Relationship between labile protein extraction and VSC emission

Relationship between headspace methane emission and VSC emission

The degradation of organic sulphur compounds in the biosolids headspace by methanogens was proposed and explained by Higgins *et al.* (2003). These researchers showed that chemical inhibition of methanogenesis in digested biosolids resulted in a substantially greater increase in volatile sulphur production than in the uninhibited control, suggesting that methanogens played a role in deodorisation. The researchers suggested that the methanogens demethylated the volatile organosulphur groups and converted them to inorganic sulphides (that remained in the biosolids as a precipitate).

Figure 3 shows the relationship between headspace methane emission rate and peak methanethiol and DMS emission (Murthy *et al.*, 2003). The figure shows that a decrease in headspace methane emission rate increases the peak VSC emission, suggesting that partial (and relative) inhibition of methanogenesis may influence VSC emission. The relationship between methane emission rates and VSC emission was especially clear for the high-solids centrifuge runs. These results corroborate the findings of Higgins *et al.* (2003). It is of interest that there is a wide range of methane emission rates for both the high- and low-solids centrifuge runs. Many of the high-solids centrifuge runs were at much higher cake solids concentration than the low-solids centrifuge runs. The higher cake contents should ordinarily produce higher methane emission rates. Despite the higher cake solids content, the methane production rates for high-solids centrifuge runs were consistently lower (about half) than biosolids obtained from the low-solids centrifuge runs.

Strategies for land application of high-solids centrifuge dewatered biosolids

Centrifuges are usually a good choice for dewatering digested biosolids prior to incineration or heat drying. They may also be the optimum selection for landfilling biosolids,

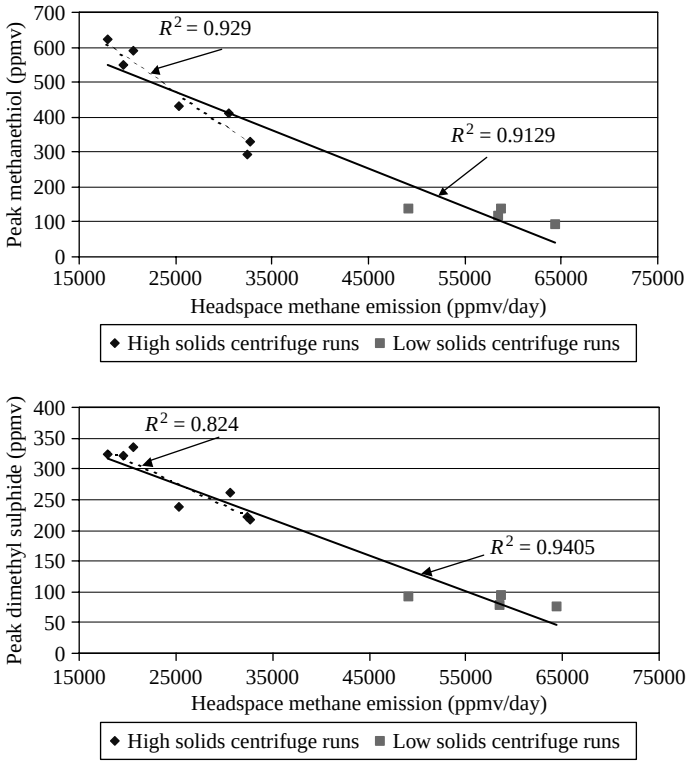

Figure 3 Relationship between headspace methane emission and peak VSC emission

especially if landfilling is conducted soon thereafter. The choice of high-solids centrifuges for land applying digested biosolids, a predominant management venue in North America, depends on several factors as shown below.

High unit cost for land application. High-solids centrifuges are chosen when the unit costs for land application are high enough to warrant land application of biosolids despite potential odours. This strategy may backfire on a utility if public opposition occurs due to odorous biosolids.

Availability of remote locations to mitigate odour impacts. High-solids centrifuges are chosen when remote sites are easily available and do not require hauling huge distances. A cost/benefit evaluation would be required to verify whether this is an economical option. Land application at remote locations that are further away from the plant site may result in a higher unit cost for land application, eliminating any savings that result from obtaining higher cake solids.

Availability of additional similar unit cost options for managing biosolids. High-solids centrifuges are chosen when programme are diverse enough to handle the biosolids through other options such as landfilling and incineration at similar or lower unit costs.

Ability to operate the centrifuges at lower shear settings. High-solids centrifuges are chosen when flexibility is available to operate centrifuges at lower rpm and/or load settings to minimise cake shear causing odorant production. Specifying this flexibility during design may be useful for plant operations (Higgins *et al.*, 2005).

Ability to enhance or extend digestion to degrade odour precursors such as residual protein. When considering high-solids centrifuges as part of an overall biosolids management plan, a utility should evaluate the use of enhanced digestion processes. As shown in Figure 4, a thermophilic process can reduce odorant production. Processes such as thermophilic digestion or thermal/mechanical or chemical disintegration can produce additional VS destruction compared with mesophilic digestion, thus more completely destroying the bioavailable odour producing protein precursors for odorant production. These processes minimise solids production and increase gas production, which are beneficial to a utility. Some of these processes provide additional benefits, such as destruction of pathogens. Another option is to extend digestion solids retention time (SRT) well beyond the 20-day average, which is an anaerobic digestion SRT considered

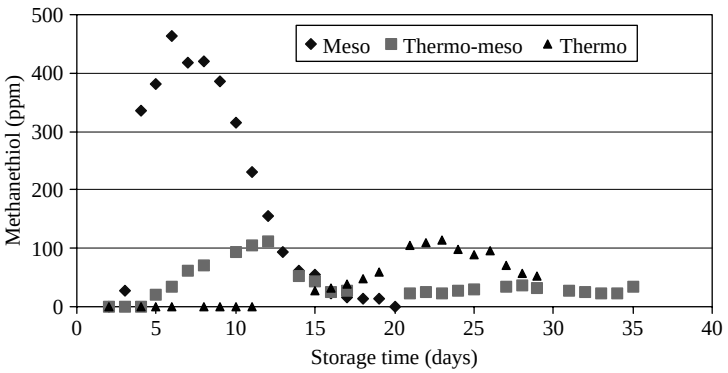

Figure 4 Evaluation of digestion methods and impacts on biosolids odours during storage

sufficient in the United States to produce a stable product. This increase in SRT could be achieved through recuperative thickening or building additional digesters.

Ability to add odour inhibitors and odour retardants. A utility with high-solids centrifuges should consider adding amendments, such as ferric chloride, that can retard odorant production through protein binding (Higgins *et al.*, 2002b). Other odour inhibitors, such as fly ash with higher carbon content, have also been somewhat successful.

Conclusions

High-solids centrifuges are a leading edge technology for use at utilities for increasing cake solids. Before considering this technology for land application of anaerobically digested biosolids, the following conclusions should be considered:

(1) The type of dewatering equipment impacts VSC emission characteristics considerably. For the same cake solids (25–26%) content obtained from the dewatering equipment (high-solids centrifuge, low-solids centrifuge and BFP simulator), the highest amount of VSC was generated from cakes produced from the high-solids centrifuge. No detectable VSC emission was observed for stored cakes obtained from the BFP simulator. A moderate amount of VSC was generated from the cake obtained from the low-solids centrifuge.

(2) Experiments were conducted to establish relationships between labile protein extraction, headspace methane emission and peak methanethiol and DMS emission. Labile protein extractions were positively correlated with VSC emission. Headspace methane emission rate was negatively correlated to VSC emission. These experiments strongly suggest that an odour cycle composed of production and degradation pathways exists for these odour compounds. Odour mitigation techniques should focus on reducing the production and emission of odorants as well as on improving degradation of odorants as already described in this paper.

Significance

This paper discussed the odour production during solids processing in high-solids centrifuges, a leading edge biosolids management issue for a leading edge dewatering technology in the United States. In the United States, the authors estimate that between $5 and $8/wet tonne surcharge for poorer product quality eliminates any volume reduction advantage of a centrifuge (high shear, high-solids device) over a belt filter press (low shear, lower-solids device). Although it is difficult to predict whether utilities have seen increases in biosolids management costs specifically because of biosolids odours, this unit cost differential is well within the range of operational unit costs for utilities managing biosolids within a similar geographic region in the United States. Utilities should consider odour impacts when considering the procurement of dewatering equipment that shear digested biosolids. If the utilities choose to procure high-solids centrifuges and continue with their land application programme, they should consider strategies to mitigate potential cake odours that could result from using the equipment.

Acknowledgements

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