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Bacterial pathogen indicators regrowth and reduced sulphur compounds' emissions during storage of electro-dewatered biosolids

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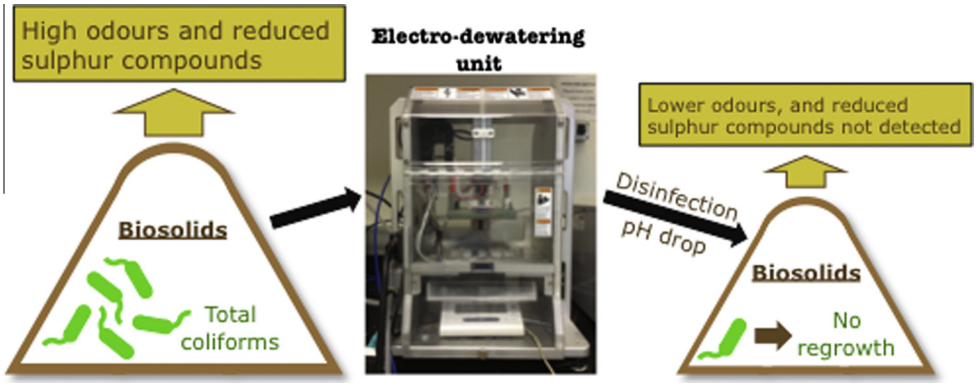
HIGHLIGHTS

- Regrowth of coliforms not observed in all electro-dewatered biosolids after 7 d.
- Regrowth of total coliforms observed in inoculated heat-treated biosolids.
- Lower odour detection and recognition thresholds for electro-dewatered biosolids.
- Little volatile organic sulphur compounds above electro-dewatered biosolids.
- pH decrease, nutrient removal and inhibitor formation may explain observed effects.

GRAPHICAL ABSTRACT



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ABSTRACT

Electro-dewatering (ED) increases biosolids dryness from 10–15 to 30–50%, which helps wastewater treatment facilities control disposal costs. Previous work showed that high temperatures due to Joule heating during ED inactivate total coliforms to meet USEPA Class A biosolids requirements. This allows biosolids land application if the requirements are still met after the storage period between production and application. In this study, we examined bacterial regrowth and odour emissions during the storage of ED biosolids. No regrowth of total coliforms was observed in ED biosolids over 7 d under aerobic or anaerobic incubations. To mimic on-site contamination during storage or transport, ED samples were seeded with untreated sludge. Total coliform counts decreased to detection limits after 4 d in inoculated samples. Olfactometric analysis of ED biosolids odours showed that odour concentrations were lower compared to the untreated and heat-treated control biosolids. Furthermore, under anaerobic conditions, odorous reduced sulphur compounds (methanethiol, dimethyl sulphide and dimethyl disulphide) were produced by untreated and heat-treated biosolids, but were not detected in the headspaces above ED samples. The data demonstrate that ED provides advantages not only as a dewatering technique, but also for producing biosolids with lower microbial counts and odour levels.

1. Introduction

Production of biosolids and their handling and disposal costs have increased substantially over the past few decades (Higgins et al., 2007). One of the most common methods for biosolids disposal is land application. According to the United States Environmental Protection Agency (USEPA) regulations, biosolids can be land applied if they fall under Class A or Class B, which are defined based on the levels of specific bacterial, viral and eukaryotic indicators (USEPA, 2003). In Canada, regulations follow similar principles and approaches (CCME, 2010). Another obstacle for biosolids land

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application is nuisance odours. While the USEPA does not regulate biosolids odour production for land application, certain Canadian jurisdictions categorize fertilizing biomaterials into four groups from less odorous than cow manure to more odorous than pig manure. Biosolids in the latter category cannot be land applied. Municipal biosolids are typically classified between cow and pig manures (Hébert, 2008). In addition to specific regulatory restrictions, emissions of odours during biosolids storage may irritate populations living close to treatment plants or land application sites. This could reduce public support for land application and limit the flexibility which operators have for biosolids management.

Electro-dewatering (ED) is a relatively new technology that can increase the solids content of biosolids up to 70 wt%, while using less energy than heat drying. It has been shown to reduce total coliforms and *Escherichia coli* to below detection limits, producing Class A biosolids (Esmaeily et al., 2006; Saveyn et al., 2006; Navab-Daneshmand et al., 2012), however, the USEPA regulations on the microbiological requirements for biosolids, mentioned above, are to be met at the time of application, and not immediately after the process. Low bacterial counts after treatment processes do not guarantee that inactivation is irreversible, and regrowth can occur during storage. For example, centrifuged anaerobically digested biosolids have shown increases of 2–4 logs of faecal coliforms and *E. coli* when incubated at 25–37 °C for 24 h (Higgins et al., 2007; Qi et al., 2008). Regrowth of bacterial pathogen indicators by several orders of magnitude during storage can be affected and controlled by several environmental parameters. One such factor is biosolids moisture content, as lower bacterial pathogen growth rates are expected in drier environments. A second factor that could impact bacterial regrowth is the availability of oxygen as an electron acceptor. Typically, biosolids are stored in deep containers or in large piles. The surface layer of the pile is aerobic due to atmospheric exposure. Oxygen diffusion, however, is limited downwards and it penetrates only a few centimeters from the surface, resulting in anoxic or anaerobic conditions lower down (Yamada and Kawase, 2006). A third factor affecting bacterial regrowth is the pH of the sludge matrix. The ambient pH affects nutrient availability and changes the solubility of substances consumed by or inhibitory to bacteria; it directly impacts microbial metabolism and enzyme activities (Sidhu et al., 2001). There is an optimal pH for microbial growth that is specific for each species; for example, *E. coli* growth rate increases by 4–5 times from pH 4 to pH above 6 (Presser et al., 1997). During ED, a pH gradient is developed in the sludge cake from low pH near the anode (as low as 2.2; Huang et al., 2008), to high pH near the cathode (as high as 7.7; Navab-Daneshmand et al., 2012). This pH gradient is generated by electrolysis on the electrode surfaces that produces hydrogen ions at the anode and hydroxide ions at the cathode. We are not aware of regrowth studies for ED biosolids, but regrowth has been shown to be substantial for biosolids from other sources such as anaerobic digestion. Thus, the first objective of this work is to determine the effect of ED treatment on the regrowth of bacterial pathogen indicators during storage.

It has been noted that ED produces biosolids with less objectionable odours (Eschborn et al., 2011; Bureau et al., 2012), but detailed information was not reported. Several classes of compounds have been identified as the causes of odours from biosolids; the main class is volatile organic sulphur compounds (VOSCs) including methanethiol (MT), dimethyl sulphide (DMS) and dimethyl disulphide (DMDS) (Murthy et al., 2003; Forbes et al., 2004; Krach et al., 2008). These compounds are commonly reminiscent of sewer odours, and they have a very low odour threshold. The VOSCs are formed from precursors released during the breakdown of readily extractable proteins in biosolids, including cysteine and methionine, that are subsequently degraded to MT and hydrogen sulphide (Higgins et al., 2006). While some authors have argued that DMDS formation was the result of abiotic oxidation of MT in the presence of molecular oxygen (Higgins et al., 2006), the presence of DMDS under strict anaerobic conditions has also been reported (Turkmen et al., 2004). Another important class of odorants is amines and ammonia that cause fishy odours. They were reported to be the main contributors to the odour profile of lime-stabilized biosolids (Kim et al., 2003). The high acid dissociation constant (typically $pK_a > 9$) of protonated amine groups means that a high pH is required for the efficient volatilization of these compounds, as it is the non-ionized form that is volatile (Chang et al., 2005). Finally, a third group of compounds responsible for biosolids odours is volatile fatty acids, which contribute to rancid or vinegary odours (Rosenfeld et al., 2001; Murthy et al., 2003). They are, however, typically considered to be minor contributors. In addition, the source, dewatering process and conditioning of biosolids impact the availability of precursors to the formation of odorants and the levels of oxygen that modulate biotic and abiotic pathways of odorant formation (Forbes et al., 2004; Murthy et al., 2006).

There have been few – if any – comprehensive descriptive or quantitative data on odours or odour classes from ED biosolids in the published literature. Thus, the second objective of the current study is to establish the principal differences in odour generation during storage between untreated and ED biosolids.

In this study, ED biosolids were compared to untreated biosolids, and to heat-treated biosolids because it had been shown that heat was the main inactivation mechanism during ED (Navab-Daneshmand et al., 2012). Regrowth was studied under both aerobic and anaerobic storage conditions. Additionally, to mimic possible contamination with bacterial pathogen indicators from raw biosolids at treatment plants or during transport, some ED and heat-treated samples were inoculated with untreated biosolids before incubation. Odour production was investigated only under anaerobic conditions because they typically favor odour production. Odour profiles after 7 d of incubation were assessed by olfactometric tests, and the dynamics of selected VOSCs concentrations were determined by a GC–MS assay.

2. Materials and methods

2.1. Biosolids

Biosolids were sampled from an activated sludge wastewater treatment plant without primary clarification near Montréal (Québec, Canada). The plant treats a flow of ~60 000 $m^3\ d^{-1}$ on average, with a hydraulic retention time (HRT) of ~12 h, and a solids retention time of ~6 d. At the time of the study, a cationic polymer (PAM C-65 L; Jes-Chem, Guelph, Ontario, Canada) was added at a concentration of 10–15 kg t^{-1} of solids before the centrifuge dewatering units. Biosolids samples were taken immediately after centrifugation, brought to the laboratory on ice and stored at 4 °C for up to 4 d.

2.2. Electro-dewatering and heat treatment of biosolids

The laboratory ED unit was a CINETIK CK-lab model (Ovivo, Boucherville, Québec, Canada), which used a direct current electrical field. Similarly to our previous study (Navab-Daneshmand et al., 2012), the maximum voltage and current were set at 60 V and 5.5 A, respectively. For each ED experiment, 165 wet g biosolids were placed on a filter medium (100% PPS Ryton, woven) over a stainless steel perforated cathode. The ceramic-coated titanium anode applied 140 kPa constant pressure. The 10 min ED cycle reduced total coliforms to below detection limits.

Heat-treatment was the control process as it had been shown that the inactivation of bacterial pathogen indicators during biosolids ED is due to high temperatures (>75 °C; Navab-Daneshmand