ARTICLE IN PRESS

Waste Management xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Assessment of co-composting of sludge and woodchips in the perspective of environmental impacts (EASETECH)

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ARTICLE INFO

Article history:
Received 21 January 2015
Accepted 14 April 2015
Available online xxxx

Keywords:
Co-composting
Sludge
Environmental impact
Life cycle assessment (LCA)
EASETECH

ABSTRACT

To reveal potential impacts to environment and human health quantitatively, co-composting and utilization of sludge and woodchips were investigated using a life-cycle-based model, EASETECH. Three scenarios were assessed through experiments using different material ratios. Emission amounts during co-composting were determined by monitoring data and mass balance. With 100 t sludge treatment, co-composting showed impacts to acidification (29.9 PE) and terrestrial eutrophication (57.7 PE) mainly for ammonia emission. Compost utilization presented savings on freshwater eutrophication (−1.5 PE) because of phosphorus substitution. With the application of fewer woodchips, impacts to acidification and terrestrial eutrophication decreased because more ammonium was reserved rather than released. All impacts to human toxicity were not significant (8.2 ± 0.6 PE) because the compost was used for urban landscaping rather than farming. Trace gaseous compounds showed marginal impacts to global warming and toxicity categories. The results provide a new perspective and offer evidence for appropriate sludge treatment selection.

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1. Introduction

With the growth of urbanization, the generation of sewage sludge is increasing rapidly. In China, over 20 million tons of sewage sludge (wet weight) is produced per year (Xu et al., 2014). In Europe, the number is even larger as more than 10 million tons of sewage sludge in dry matter is produced every year (Rodriguez et al., 2012). Sludge disposal options are normally adjusted to local conditions, including geographical, legal, and economic circumstances, with the most widely available ones being agriculture utilization, waste disposal sites, land reclamation and restoration, incineration, and other novel uses (Fytili and Zabaniotou, 2008). Before utilization and disposal, municipal sludge normally has to be dewatered and/or treated to eliminate the bacteria, viruses, and organic pollutants; many technologies including dewatering, anaerobic digestion, and aerobic composting have thus been developed (Dong et al., 2014). Among these technologies, composting followed by land application is one of the most appropriate ways for economical sludge treatment and disposal (Wong et al., 2011).

However, because of its compacted structure, high water content, and low C/N ratio, municipal sludge can hardly be composted by itself (Banegas et al., 2007). Co-composting of municipal sludge and other materials, including municipal solid waste (Lu et al., 2009), saw dust (Yousefi et al., 2013), and food industry waste (Ammari et al., 2012), is therefore promising given their complementary characteristics. Garden waste, which normally has loose structure, low water content, and high C/N ratio, is widely applied in co-composting with sludge (Albrecht et al., 2010; El Fels et al., 2014). However, considering that one of the main aims of the bioprocess is to treat waste and reduce its environmental impacts, pollutant emissions and environmental impacts during the co-composting are always key concerns. Of utmost concern is the fact that land application of sewage sludge and its compost entails risks on ecological safety due to potential accumulation of toxic elements (Singh and Agrawal, 2008; Sreesai et al., 2013).

To better understand the potential impacts to the environment, life cycle assessment (LCA) of sewage sludge treatment has been gaining ground (Yoshida et al., 2013). LCA can systematically and effectively evaluate the potential environmental burden associated with energy consumption, process, product, and substitution during sludge treatment (Hong et al., 2013). In the current paper, based on pilot experiments focusing on parameters such as material ratios, temperatures, and changes in water content, the

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http://dx.doi.org/10.1016/j.wasman.2015.04.021
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Please cite this article in press as: Zhao, Y., et al. Assessment of co-composting of sludge and woodchips in the perspective of environmental impacts (EASETECH). Waste Management (2015), http://dx.doi.org/10.1016/j.wasman.2015.04.021

co-composting of municipal sludge and garden waste was assessed in the perspective of environmental impacts by using a newly developed LCA-based tool called EASETECH. This model software can perform life cycle assessment of complex systems involving different environmental technologies in the perspective of environmental impacts, with especial professional function for solid waste system modeling. By using this model, the current study can reveal the life cycle inventories and impact potentials of different co-composting operations, by investigating and assessing their emissions and material and energy consumption. The results provide important supplement to technical study for better understanding the environmental benefits or burdens of the co-composting process, as well as provide a new perspective and offer evidence for choosing the proper operations or technologies for municipal sludge treatment.

2. Materials and methods

2.1. Composition of materials

The municipal sludge used in the current study was produced and dewatered in a municipal wastewater treatment plant in Suzhou, China. Garden waste was collected from urban landscaping projects, from which clipped branches were selected and crushed into woodchips that were 2–3 cm in length and 3 mm thick. The compositions of the sludge and woodchips were analyzed in the laboratory prior to composting, as shown in Table 1.

2.2. Co-composting technology description and experimental design

Pilot experiments of co-composting were carried out in a biotechnology company with a treatment capacity of 100 t sewage sludge per day in Suzhou, China. Windrow process was used with turning over by an upender. The sludge and woodchips were first weighed and mixed until well-distributed. Subsequently, over 5 tons of the mixed waste was windrowed, with length, width, and height of 5, 1.8, and 1 m. Co-composting processes were operated for 45 days, during which the mixed waste was turned over about once in every 4 days.

Three experimental batches (A, B, and C) of co-composting were implemented, with mass ratios (in wet weight) between sludge and woodchips of 3:1, 4:1, and 5:1, respectively. During the co-composting, the temperatures, percentages of CH_4 and CO_2, and releasing rates of NH_3 were measured once per day in the first 30 days, and then once every 2 days in the remaining 15 days given that the decomposition rates became slower in the second half of the periods. For the same reason, the volatile solid (VS) of the mixed waste was measured once every 2 days in the first 30 days and once every 4 days in the remaining 15 days by mixing of triple parallel samples. The concentrations of CO_2 and CH_4 were monitored daily. The daily distribution of CO_2 and CH_4 (the percentage of everyday CO_2 and CH_4 amounts in terms of total volume of CO_2 and CH_4) was thus calculated according to the VS monitoring data during the processes, with the idea that the volume of CO_2 and CH_4 was produced from VS decomposition proportionally. The water content, VS, and compositions, including nutrient elements, heavy metals, and germination indexes of each batch, were analyzed at the end of the experiments. Based on the element analysis before and after co-composting experiments, the proportions of C and N in the sludge, woodchips, and compost can be determined and used to calculate the C and N losses. Furthermore, gaseous emissions during the first batch of co-composting were parallel sampled using polyester bags and analyzed to reveal the impact contributions of the trace gases. Thirty odorous pollutants, such as toluene, dimethyl sulfide, limonene, and 1,2-dichloro-ethane, were determined as shown in Section 3.3.

Table 1
Compositions of raw sludge and woodchip.

Item	Sludge	Woodchip
Water (%)	84.63 ± 0.01	24.73 ± 0.12
VS (%TS)	62.24 ± 0.27	94.05 ± 1.33
C (%TS)	29.17 ± 0.28	37.34 ± 2.18
H (%TS)	4.78 ± 0.07	5.02 ± 0.23
N (%TS)	4.40 ± 0.08	1.64 ± 0.33
Cd (%TS)	1.717×10^{-3}	Not detected
Cr (%TS)	5.620×10^{-3}	2.786×10^{-3}
Cu (%TS)	1.623×10^{-2}	2.647×10^{-3}
K (%TS)	0.6516	0.7348
Ni (%TS)	2.771×10^{-3}	2.169×10^{-3}
P (%TS)	1.260	5.721×10^{-2}
Pb (%TS)	1.473×10^{-3}	5.352×10^{-2}
Zn (%TS)	6.291×10^{-2}	9.353×10^{-3}

2.3. Analysis method

The water contents and VS of the waste were determined by weight method using a drying oven and a muffle furnace. Elements of C, H, and N were analyzed using an Elemental Analyzer CE440 (Exeter Analytical, Inc., USA). Elements of P, K, and heavy metals listed in Table 1 were analyzed through inductively coupled plasma–atomic emission spectrometry (ICP-AES, IRIS intrepid, Thermo Electron Co., USA). Concentrations of CH_4 and CO_2 were monitored *in situ* (20 cm beneath the surface to avoid air interference) by using a biogas analyzer (Geotech Biogas 5000, Shanghai Zhonglin Co., China). The release rates of NH_3 were measured by using a static chamber technique and a multiple gas analyzer (Dräger X-am 7000, Drägerwerk AG & Co., Germany). The trace compounds in gaseous emissions were analyzed by a gas chromatography–mass spectrometer (GC–MS) system (Agilent 7890A-5975C, Agilent Technologies, Inc., USA). The germination test was carried out and the germination index was calculated according to the method reported by Roca-Pérez et al. (2009). The temperatures and pH were monitored routinely.

2.4. Model description and scenario setup

Based on the experimental data from co-composting of sludge and woodchips, the data related to life cycle assessment of the processes were investigated and then modeled with an LCA-based model called EASETECH. EASETECH is an LCA model for the assessment of environmental technologies newly developed at the Technical University of Denmark (Clavreul et al., 2014). EASETECH can perform life cycle assessment of complex systems handling heterogeneous material flows, with professional function for solid waste system modeling. With a focus on material flow modeling, resource use and recovery, as well as environmental emissions associated with environmental management systems can be modeled in a life cycle context. Related data are first input for all the process libraries including waste generation, collection and transportation, various treatment and disposal technologies, resources and recovery technologies, and related upstream and downstream processes. Subsequently, scenarios are created by connecting related processes from the libraries to represent systems to be modeled. The program of EASETECH then uses data contained in the scenario to compute results (Clavreul et al., 2014). The results can be provided in four levels, namely, life cycle inventory, characterization, normalization, and weighting, presenting impacts to 10 environmental categories, including global warming 100 years (GW100), terrestrial acidification (AC), freshwater eutrophication (FEP), terrestrial eutrophication (TEP), marine eutrophication (MEP), stratospheric ozone depletion 100 years

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