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Biofiltration treatment of odors from municipal solid waste treatment plants

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ABSTRACT

An in situ compost biofilter was established for the treatment of odors from biostabilization processing of municipal solid waste. The concentrations of total volatile organic compounds (VOCs) in odors and their components were measured. Biofilter media was characterized in terms of total carbon (TC), total nitrogen (TN), total phosphorus (TP), organic matter (OM), pH value and determination of bacterial colony structure. Gas chromatography–mass spectrometry (GC–MS) analysis showed that the main components of the produced gas were benzene, toluene, ethylbenzene and xylene (BTEX) along with other alkanes, alkenes, terpenes, and sulphur compounds. The compost biofilter had remarkable removal ability for alkylated benzenes (>80%), but poor removal for terpenes (~30%). Total VOC concentrations in odors during the biostabilization process period ranged from 0.7 to 87 ppmv, and the VOC removal efficiency of the biofilter varied from 20% to 95%. After about 140 days operation, TN, TC, TP and OM in compost were kept almost stable, but the dissolved N, NH_4–N and NO_3–N experienced an increase of 44.5%, 56.2% and 76.3%, respectively. Dissolved P decreased by 27.3%. The pH value experienced an increase in the early period and finally varied from 7.38 to 8.08. Results of bacterial colony in packing material indicated that bacteria and mold colony counts increased, but yeasts and actinomyces decreased along with biofilter operation, which were respectively, 3.7, 3.4, 0.04 and 0.07 times of their initial values.

1. Introduction

Biological mechanical treatment (BMT), including biostabilization and mechanical separation process, is a rapidly developing pretreatment technology for municipal solid waste (MSW) prevalent in Europe due to the EU Landfill Directive of April 1999 (99/31/EC) (Lornage et al., 2007; De Araujo Morais et al., 2008). In BMT process, odors are generated due to organic matters decomposition and anaerobic fermentation, especially when insufficient oxygen is available. According to Eitzer (1995), principle volatile organic compounds (VOCs) from MSW composting facilities include aromatic hydrocarbons, D-limonene, chlorinated compounds, and ketones. Smet et al. (1999) found that alcohols, carbonyl compounds, terpenes, esters, sulphur compounds and ethers were present in aerobic composting waste gases. Pierucci et al. (2005) identified the most important compounds in effluent gas from biological treatment of MSW were terpenes, monocyclic arenes (C2, C3 and C4 benzenes), alkanes, halogenated compounds and esters.

Biofiltration is a viable control technology based on its low cost and non-generating of hazardous residue and interesting ability to remove odorous compounds (Mohseni and Allen, 2000; Rappert and Müller, 2005; Nevin and Barford, 2000). Several recent studies have reported effective elimination of VOCs, such as ethylbenzene (Alvarez-Hornos et al., 2008), benzene (Zilli et al., 2005), styrene (Jorio et al., 2000) and toluene (Rene et al., 2005) using biofilters.

In a biofilter, a contaminated/odorous gas stream passes through a biologically enriched layer of a filter material such as soil, wood chips, compost or mixed materials, followed by biodegradation of the adsorbed pollutants (e.g. Chung et al., 2005; Pagans et al., 2007a). Absorption should be considered as an important mechanism of pollutant removal in the biofilter, especially when highly soluble pollutants are treated (Pagans et al., 2007b).

The characteristic of the filter medium has been reported as one of the key factors in biofilter performance (Alvarez-Hornos et al., 2008). Many solid organic materials have been used as packing media, such as compost, peat and soil. In comparison with other media, the major advantages of mature compost are inexpensive and readily available (Swanson and Loehr, 1997). However, nutrient depletion is often encountered in compost-based biofilter during a long-term operation although it has significant amounts of organic nitrogen and other micronutrients (Hwang et al., 2007). Such is often the case when nitrogen is in a less accessible form (e.g., as organic rather than as inorganic nitrogen) (William and Robert, 2001). Morgenroth et al. (1996) found that hexane removal efficiency of a compost biofilter were under 80% until addition of

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nitrate solution. Some researches also indicated that ammonia gas injection could recover biofilter performance and increase VOCs removal efficiency (Morales et al., 1998; Wu et al., 2006). Abundant of diverse microbial communities such as bacteria, molds, yeasts and actinomyces is another advantage of compost medium which can facilitate the start-up and reduce the acclimation period of a biofilter. Microorganisms in mature compost possess the ability to degrade various odorous compounds (Morgenroth et al., 1996; Rene et al., 2005; Zilli et al., 2005). Chuang (2007) revealed that *Proteobacteria*, *Actinobacteria*, *Bacteroidetes* and *Firmicutes* were predominant in the biofilter for composting exhaust air purification. Fungi were also employed in biofilters for VOCs degradation (Cox et al., 1997; García-Peña et al., 2001).

Although compost-based biofilters have been widely utilized to remove single or mixtures of several contaminations in laboratory-scale test, the performance of compost biofilter for field-scale odorous gases removal from MSW BMT processing plants has not been further investigated.

In this study, a compost biofilter was established at Shanghai Pudong Meishang MSW Biochemical Treatment Company (Gong Road, Caolu town, Pudong New Area, Shanghai, China), where BMT pretreatment and composting processes were used for MSW disposal. The compost biofilter was evaluated for the treatment of effluent gases from the MSW BMT plant under various operating conditions. The main components of odorous compounds, which included the regulatory compliance components, from biostabilization processing were monitored and the characteristics changes of compost media in biofilter were analyzed. In addition, enumeration of bacteria, molds, yeasts and actinomyces present in the filtering bed was performed in order to follow the evolution of these microorganisms.

2. Materials and methods

2.1. Meishang MSW treatment process and MSW composition

Technological process of BMT treatment is shown in Fig. 1. MSWs are piled in stacks with the height of 1.8–2.0 m. The biostabilization process lasts about 20 days during which air supplied by fans flow through the stacks from bottom to the top at the rate of 0.2 $m^3\ m^{-2}\ min^{-1}$ continuously. To ensure even distribution of air, perforated pipes (10 cm diameter with 1 cm diameter holes) are used. Following the aeration phase, MSWs are transported to mechanical separation process to remove plastic, glass, metal, bricks and other noncarbonaceous wastes and the remainder is sent to aerobic compost for another 40 days forming mature compost.

Average composition of MSWs processed at the plant is shown in Table 1. The waste is of high moisture content (50–60%) and low calorific value (about 1000 kcal/kg), containing a large percent of organic garbage (Table 1).

2.2. Biofilter system and packing media

As shown in Fig. 2, an upward flow biofilter was employed in this study. The biofilter was made of a transparent plexiglass cube with 600 × 600 × 800 mm, and filled with 500 mm of packing media resulting in a bed volume of 180 L. A plexiglass perforated plate with 3 mm diameter holes on 10 mm centers supported the media. Ceramic particles were placed in the bottom plenum to evenly distribute airflow entering the biofilter. Gas sampling ports were located at 75 mm (inlet port) form the bottom and 725 mm from the bottom (outlet port) for total volatile organic compound (TVOC) concentration and differential pressure measurement. Additional ports located at 250, 400, and 550 mm form the bottom were used to sample packing materials for physico-chemical properties and bacterial enumeration.

Odors from the MSW biostabilization process was collected by a gas trap hood placed on the composting pile, and conveyed with 40 m long polyvinyl chloride pipe (inner diameter 32 mm) to the biofilter. Air flow was measured by a rotator flow meter (LZB-40, Shanghai Jiahu instrument Co., Ltd., China).

Table 1
Mass ratio of main MSW components in Meishang Company.

Component	Content (%)
Organic garbage	66.70
Paper	4.46
Plastic	19.98
Wood	1.21
Textile	1.80
Metal	0.27
Glass	2.72
Ash	2.77

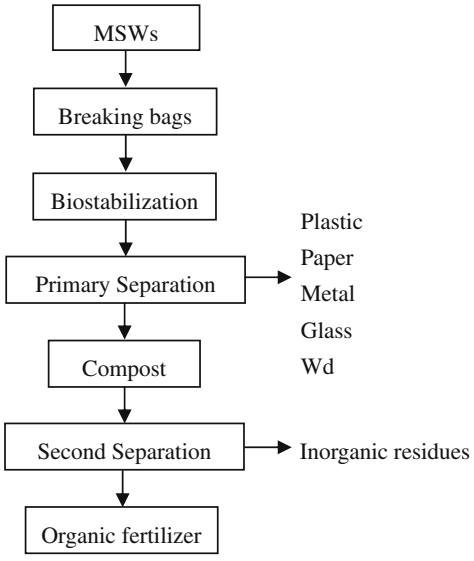

Fig. 1. Technological process of Meishang Company.

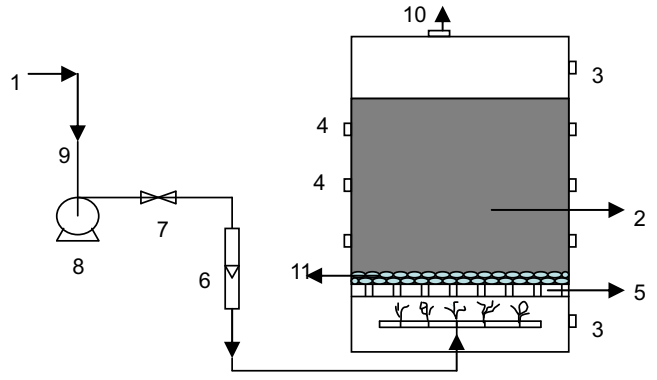

Fig. 2. Schematic diagram of the compost biofilter. (1) Odor from MSW composting, (2) compost material, (3) gas sampling ports, (4) solid sampling ports, (5) perforated support, (6) rotator flow meter, (7) valve, (8) blower, (9) 40 m PVC tubes, (10) treated air and (11) ceramic particles.

Table 2
Initial properties of biofilter media.

Parameter	Value
Total carbon (g/kg dry compost)	201.5 ± 24.7
Total phosphorous (g/kg dry compost)	5.5 ± 0.6
Total nitrogen (g/kg dry compost)	14.1 ± 1.3
Organic matter (g/kg dry compost)	210.0 ± 16.4
pH	7.16
Moisture content (%)	31.2
Particle size (mm)	3–8
Porosity (%)	32.7
Bulk density (g/cm^3)	0.572
Heavy metal content[*]	
Cu (mg/kg dry compost)	167.57–357.73
Pb (mg/kg dry compost)	97.30–192.07
Zn (mg/kg dry compost)	388.56–709.56
Cd (mg/kg dry compost)	0.60–2.42
Cr (mg/kg dry compost)	139.54–373.37
Mn (mg/kg dry compost)	551.41–1472.22
Ni (mg/kg dry compost)	30.10–97.55

[*] Provided by Meishang Company.

Mature MSW compost was used as the packing media without any microbial inoculation. The material was sieved to reject particles with a diameter less than 3 mm. The characteristics of the packing material are given in Table 2.

2.3. Biofilter operation

Experiments were performed for 140 days which covered five biostabilization cycles. Each biostabilization cycle was approximately 20 days, followed by a 7 days lag period. The biofilter was operated continuously for each cycle and intermittently during the interval between cycles. Before the start-up of each cycle, 10 L of water was added into the biofilter to prevent drying of compost media. According to different empty bed residence time (EBRT, defined as biofilter volume occupied by packing material divided by the airflow rate), the whole experimental operation was divided into three periods (periods I, II, and III). The EBRTs for three periods were 32.5, 40.5 and 65.0 s, which corresponded to gas flow rate of 20, 16 and 10 m^3/h. The detailed operation conditions of each period are summarized in Table 3.

2.4. Analytical methods

This study used 3 L tedlar gas sampling bags (TPV-030, Dalian delin gas packing Co., Ltd., China) to collect odorous gas at inlet and outlet of compost-based biofilter. About 500 mL of odor samples from sampling bags were cold trapped and pre-concentrated in a 7100 pre-concentrator (Entech Instruments Inc., USA), then thermally desorbed into the gas chromatography–mass spectrometry (GS–MS) system (Agilent 6890GC/5973MS) for VOC identification and quantification. A 60 m 100% dimethyl polysiloxane column (film thickness 1.0 μm, internal diameter 0.32 mm) was temperature programmed from 40 °C for 2 min, raised at 6 °C/min to 250 °C and held for 10 min. Mass spectrometer conditions were as follows: temperature of the transfer line: 280 °C; ionizing energy: 70 eV; scan range: 46–500 me^{-1}.

Table 3
Operation conditions of each period in the biofilter system.

Period number	Operation time (days)	TVOC concentration (ppmv)	Gas flow rate (m^3/h)	EBRT (s)
I	0–77	0.68–87.2	20	32.5
II	87–106	3.3–68.3	16	40.5
III	116–140	2.6–64.9	10	65.0

TVOC concentration was measured using a portable photo ionization detector (RAE Model PGM-7240, RAE system Inc., USA). All data were recorded by the instrument at the frequency of one data per minute during the sampling period.

Total nitrogen (TN) and total carbon (TC) of packing material were determined using an elemental analyzer (EuroEA3000, Italy). Total phosphorous (TP) was analyzed by spectrophotometry method after digestion with hydrofluoric acid and perchloric acid (Zhang et al., 2004). Organic matter (OM) was determined according to potassium dichromate oxidation, ammonium ferrous sulfate titration (Walkley–Black method). In order to investigate the variations of some chemical composition in compost media, aqueous extracts of the media were obtained by shaking mechanically with mixture of deionized water and packing media of 40:1 (v/w) for 1 h. The following measurements were carried out on the filtrate: NH_4^+–N was analyzed by the spectrophometric method using Nessler reagent (Chen et al., 2005). Soluble total nitrogen was analyzed by spectrophotometric method after digestion with potassium persulfate; Soluble total phosphorous was analyzed by ammonium molybdate spectrophotometric method; and NO_3^-–N (including NO_2^-–N) was analyzed by spectrophotometric method with phenol disulfonic acid (Bao, 2000). The numbers of various microorganisms in compost were analyzed using plate count method. Beef extract peptone agar media were used for bacteria (Wu et al., 2006). Gasae's No. 1 synthetic agar media was used for actinomyces (Li et al., 2008). Potato dextrose agar media were used for yeasts (Wu et al., 2006). Molds were detected using Czapek's media (Li et al., 2008). The cell number of bacteria, actinomyces, yeasts and molds were determined by serial dilution. Only plates with 30–300 colony forming units (CFUs) were counted. Microbial concentration results are reported as the number of CFUs per unit mass of dry compost medium. These analyzes were carried out in triplicate and results given are the averages with standard deviations.

Porosity of packing material was determined using a water pycnometer. Bulk density of packing material was measured using an approximately 5-L volume container. The container was filled with material, and then the material was slightly compacted to ensure absence of large void spaces. The bulk density can be calculated by dividing the weight of the material by the volume of material in the container.

The pH values of the packing media were measured as follow: 5 g packing media was taken from each solid sampling port and 45 ml sterilized water was added to each compost sample. The solution was measured with an electrical pH meter (pHS-3C, Shanghai Ridao Scientific Instrument Co., Ltd, China).

Periodic measurements of pressure drop across the packing media were made using a U-tube water manometer (Shanghai huxi analysis instrument factory, China) and the readings can be used to monitor the clogging and compaction of packing materials.

3. Results and discussion

3.1. Biofilter performance for TVOC

The concentration of TVOC emitted from MSW biostabilization process ranged from 0.68 to 87.2 ppmv during the operation period of biofilter. The overall biofilter performance for TVOC was shown in Fig. 3. TVOC concentrations in each cycle showed a decreasing trend with time. Peak concentrations were detected on third or 7th day (Fig. 3). High TVOC concentration in early stage of processes could be the results of high microorganism activity. Similar results were reported by Eitzer (1995) and Pagans et al. (2006).

As one can see in Fig. 3, the TVOC removal efficiency of biofilter ranged from 20% to 95%, and higher TVOC reduction was obtained during the later stage of MSWs biostabilization when TVOC con-

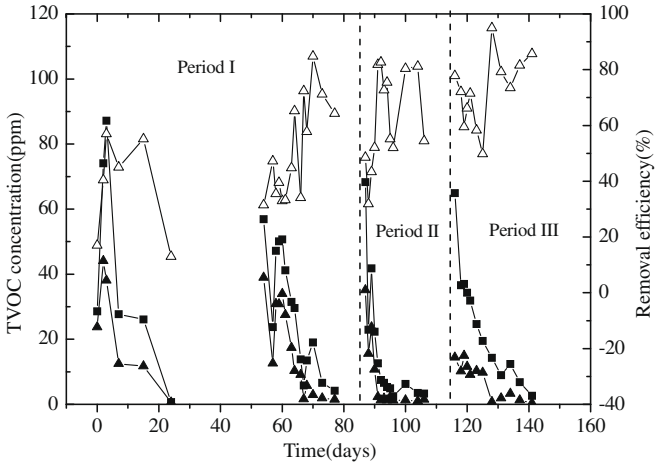

Fig. 3. Overall performance of the compost biofilter for the removal of TVOC, inlet concentration (solid squares); outlet concentration (solid triangles); removal efficiency (triangles).

centration was at low level. Performance of the biofilter could also be influenced by the components in odorous exhaust. According to Eitzer (1995), some compounds not easily degraded by microorganism, including trichlorofluoromethane and 1,1,1-trichloroethane, were emitted mainly in the early stage of composting. However, bioavailably degraded compounds such as acetone and 2-butanone became prominent in latter periods. Pagans et al. (2007a) found poor VOC removal efficiency was obtained during the final stages of composting due to the VOCs released by compost media itself. However, in this experiment, the TVOC amount discharged by packing materials was founded to be negligible (data not shown).

As shown in Fig. 3, the increase of EBRT had an obverse effect on the TVOC removal efficiency of the system. The compost-based biofilter seemed to perform better at higher EBRT due to increasing contact time between contaminated air and packing media. When the EBRT was 65.0 s, 49.8–95.0% removal efficiency was observed, compared to 20.0–84.8% for 32.5 s and 31.9–82.7% for 40.5 s.

The influence of loading rate on elimination capacity of compost-based biofilter in various operation conditions is shown in Fig. 4. The solid line indicates 100% elimination capacity of biofilter for inlet VOC. *n*-Hexane was selected to quantify VOC concentration in g C m^{-3}. The elimination capacity increased with inlet

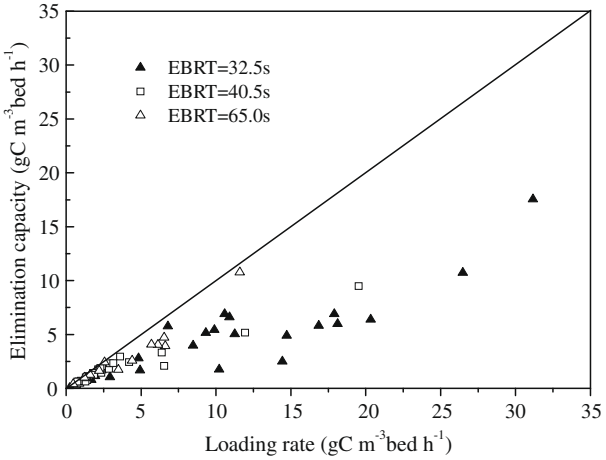

Fig. 4. Elimination capacity of the compost-based biofilter for different loading rate in various operation conditions.

VOC loading rate, especially when EBRT was 65.0 s. For a given pollutant, generally, the elimination capacity of biofilter increased with inlet loading rate until a maximum reached. This was most likely due to microbial degradation kinetic limitations (Wani et al., 1999; Chan and Su, 2008). Pagans et al. (2007a) reported a maximum VOC elimination capacity of 18.70 g C m^{-3} h^{-1} in their pilot-scale composting and biofiltration system. In our biofilter, the maximum VOC elimination capacity of 17.55 g C m^{-3} h^{-1} could be reached at a loading rate of 31.16 g C m^{-3} h^{-1}. However, this value can not be defined as the actual maximum elimination capacity because higher loading rates were not tested in our study.

3.2. VOCs emitted during MSW biostabilization and biofilter's removal ability

During the period II of biofilter operation, the GC–MS quantitative analysis of VOCs in influent and effluent gas of biofilter were carried out and 40 different chemical compounds were identified in the odorous gases from MSW biostabilization process. The prevailing groups were alkylated benzenes (ethylbenzene, xylene, toluene and ethyltoluene), followed by alkanes (*n*-decane, nonane, heptane and cyclohexane), alkenes (2-methyl-hexene, cis-2-butene, trans-2-butene and 2-methyl-2-butene), terpenes (α-pinene, β-pinene and naphthalene) and sulphur compounds (dimethyl disulfide, carbon bisulfide and dimethyl sulfide) (see Table 4).

High amounts of VOCs (alkanes and alkylated benzenes) emitted from MSW biostabilization process indicating that these compounds could be a result of decomposition (Komilis et al., 2004). Alkanes (heptane, octane, nonane and *n*-decane) concentrations reached the maximum value of 60.27 μg heptane m^{-3}, 79.56 μg octane m^{-3}, 665.53 μg nonane m^{-3} and 1060.96 μg *n*-decane m^{-3} at the beginning of ventilation and then decreased with time during the study. Hexane and cyclohexane attained peak concentration of 64.63 and 53.92 μg m^{-3} at 6th day and then decreased. Methyl-cyclohexane was measured in relatively low concentrations of no higher than 3.87 μg m^{-3} during the entire composting process. MSWs biostabilization process emitted relatively high concentrations of toluene, ethylbenzene, xylene, ethyltoluene, at the range of 73.84–728.23 μg toluene m^{-3}, 1190.67–4587.43 μg ethylbenzene m^{-3}, 1973.25–8099.69 μg xylene m^{-3} and 84.58–917.22 μg ethyltoluene m^{-3}, respectively. Different from alkane, the peak concentrations of these compounds were detected at 9th day. These compounds were also detected in similar concentrations by Komilis et al. (2004) and Turan et al. (2007) in simulative composting of the organic fraction from MSWs and poultry litter.

Alkenes were found by Komilis et al. (2004) in the exhaust from different wastes composting process. In this experiment, alkenes such as trans-2-butene and 1,3-butadiene were detected in relative low concentrations. Terpenes were the prevalent VOCs emitted from municipal solid waste composting process (Komilis et al., 2004) and can be associated with yard trimmings (Goldstein, 2002) and plants (Haug, 1993) present in the MSWs. The low concentration of terpenes detected in this experiment should be related to the small amounts of these wastes in Meishang MSWs. As sulphur compounds often result from incomplete or insufficient aeration of composting (Homans and Fischer, 1992), the low concentration of sulphur compounds detected in this experiment could be explained by sufficient aeration during the composting. Carbon disulfide and naphthalene were in negligible amounts during biostabilization process. Dimethyl disulfide concentration was maintained at the range of 33.24–41.41 μg m^{-3} until the 15th day.

Results of GC–MS quantification in period II for inlet and outlet of biofilter (shown in Table 4) indicated compost biofilteration had obvious impacts on alkylated benzenes. More than 90% removal efficiency was obtained by biofilter for most of alkylated benzenes except for benzene (88% in average) and toluene (82% in average).

Table 4
Concentrations of chemical compounds (in μg/m^3) in the influent and effluent of compost-based biofilter during period II of operation (nd means not detected).

Compounds	3rd day		6th day		9th day		12th day		15th day	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
trans-2-Butene	2.41	nd	2.39	9.80	10.98	8.56	3.55	6.39	1.36	nd
1,3-Butadiene	5.10	nd	9.72	4.14	2.31	2.40	0.31	0.23	nd	nd
cis-2-Butene	nd	nd	119.66	36.51	10.21	nd	17.65	8.23	4.30	nd
2-Methyl-1-butene	41.14	0.65	40.58	nd	48.82	3.12	1.91	nd	6.31	nd
trans-2-Pentene	89.35	nd	13.22	nd	112.6	6.81	nd	nd	15.27	nd
2-Methyl-2-butene	nd	nd	22.96	6.26	39.62	22.05	35.99	4.25	1.71	nd
2-Methyl-hexene	11.19	0.15	3.11	1.52	nd	nd	0.33	nd	0.34	nd
Hexane	13.62	0.78	64.63	4.72	2.12	3.30	2.53	0.94	0.32	nd
Methyl-cyclopentane	17.87	nd	nd	nd	2.57	nd	nd	nd	nd	nd
2,3-Dimethylpentane	44.23	0.54	15.98	6.02	49.73	9.55	3.80	nd	1.14	nd
3-Methylhexane	4.64	0.14	14.03	5.32	12.75	2.45	1.01	0.87	0.27	nd
2,2,4-Trimethylpentane	20.21	nd	1.45	0.54	7.82	0.78	10.19	0.14	0.43	nd
Heptane	60.27	9.05	5.53	nd	24.90	2.46	15.83	1.50	3.70	nd
Methyl-cyclohexane	nd	nd	nd	nd	3.75	nd	3.87	nd	nd	nd
Octane	79.56	7.83	19.03	nd	51.85	nd	13.56	nd	nd	nd
Nonane	665.53	13.63	100.58	71.57	79.28	76.00	157.23	14.57	19.62	nd
n-Decane	1060.96	1223.18	1065.09	804.58	638.41	745.05	511.78	377.85	69.06	19.59
Cyclohexane	40.21	nd	53.92	5.38	nd	nd	4.51	1.51	nd	nd
Benzene	17.06	0.71	11.34	3.70	31.87	1.67	10.47	1.10	1.23	0.05
Toluene	437.69	173.01	256.02	60.90	728.23	88.35	275.35	36.30	73.84	0.50
Ethylbenzene	2294.62	121.89	1812.79	55.86	4587.43	95.19	2602.50	88.06	1190.67	4.03
m,p-Xylene	3214.40	169.09	2522.06	77.89	6238.35	132.00	1680.26	122.24	1654.49	5.63
o-Xylene	842.33	51.24	507.64	24.89	1861.34	35.40	580.83	34.69	318.76	1.64
i-Propylbenzene	84.44	2.04	39.60	0.87	110.25	1.29	74.10	1.82	5.58	nd
Propylbenzene	57.54	31.22	38.93	14.20	32.42	13.92	33.66	1.03	4.49	nd
m-Ethyltoluene	351.47	5.53	213.12	2.38	416.55	4.04	362.52	5.08	38.67	nd
p-Ethyltoluene	332.55	5.23	201.68	10.85	394.20	3.81	343.10	4.79	36.59	nd
o-Ethyltoluene	87.42	1.73	51.03	1.22	106.47	2.23	90.53	1.59	9.32	nd
1,3,5-Trimethylbenzene	81.35	6.30	53.24	3.25	85.15	2.90	87.87	3.56	10.57	nd
1,2,4-Trimethylbenzene	296.19	8.18	200.12	3.41	248.15	4.38	285.49	9.12	23.57	nd
1,3-Diethylbenzene	5.10	0.84	4.61	nd	5.15	0.39	6.33	0.55	1.04	1.04
1,4-Diethylbenzene	34.43	1.14	32.49	nd	31.02	0.49	44.70	0.73	1.36	nd
1,2-Diethylbenzene	26.58	0.86	25.01	nd	23.86	0.38	34.46	0.57	1.04	nd
Dimethyl sulfide	29.77	0.06	2.12	1.46	28.57	1.16	nd	nd	4.30	nd
Carbon disulfide	14.67	0.10	nd	1.37	5.48	nd	1.79	nd	1.46	nd
Dimethyl disulfide	35.35	0.04	33.24	0.17	41.41	0.27	37.19	0.09	9.35	0.02
a-Pinene	73.29	40.84	50.96	18.19	42.98	18.09	4.34	0.86	4.97	0.05
b-Pinene	65.19	71.56	18.62	33.97	13.41	33.68	14.22	0.46	2.24	nd
Naphthalene	3.84	1.47	1.49	0.76	0.50	0.72	2.86	1.04	0.13	nd

For alkanes, the biofilter showed higher removal efficiency for smaller molecular weights. For example, hexane (>85.8%), pentane (>87.4%) and octane (>91%) had good removal rates compared to the higher molecular weight alkanes like *n*-decane (10% in average) and nonane (64% in average). The biofiltration system maintained more than 99% removal efficiency for sulphur compounds. However, for terpene, the biofilter possessed poor biodegradation ability (<64% for α-pinene when concentration exceed 40 μg m^{-3}, negative removal efficiencies for β-pinene in most cases, <64% for naphthalene).

3.3. Physico-chemical properties of the compost media

Nutrients in compost can markedly impact the microbial population and therefore biofilter performance. Fig. 5 shows the variations of TC, TN, TP and OM in packing media. As observed, the TN, and TP did not change significantly throughout the biofiltration process and kept the values of 14.87 ± 1.42 g kg^{-1} dry media, 5.3 ± 0.4 g kg^{-1} dry media, respectively. Slight fluctuation of TC and OM appeared in Fig. 5 might be due to the heterogeneity of compost media and sampling artifacts than actual alterations in TC and OM contents.

In order to further investigate the changes of bioavailable nutrients in packing material, the contents of soluble total nitrogen, soluble total phosphorous, NH_4^+–N and NH_3^-–N (including NH_2^-–N) in the compost media were measured. As shown in Table 5, NH_4^+–N and NH_3^-–N content in compost media increased with operation. NH_4^+–N content increased from 465.1 to 677.2 μg g^{-1} on day 120 and finally to 726.7 μg g^{-1} on day 140. This might result from the sorption of ammonia to the packing material (Park et al., 2002.). The obvious increase of NH_3^-–N indicated the possibility for nitrification occurring in the filter material. As ammonium nitrogen and nitrate nitrogen gradually accumulated, the soluble total nitrogen increased throughout the study. However, the soluble total phosphorous showed an adverse trend, decreased by 27% after 140 days of operation possibly due to the gradual transformation from soluble to insoluble phosphorous incorporated into biomass. Considering long-term operation, the soluble phosphorous should be supplemented periodically to avoid P-nutrient deficiency.

Accumulation of metabolite products of halogenated organic compounds (Kim et al., 1998) and reduced sulphur compounds (Smet et al., 1996) lead to the acidification of biofilter which decreased the removal efficiency of biofilter due to pH inhibition of biodegradation. During this experiment, the pH values of compost material remained at a near neutral range of 7.38–8.08 (Fig. 6) which was a little higher than the initial value of 7.16. Changes in pH depend mainly on the concentrations and compositions of gases emitted as well as the buffering capacity of the media. From Table 4, we can know that the halogenated organic compounds were not detected and reduced sulphur compounds were in negligible amount in the exhausted gases from the biostabilization pro-

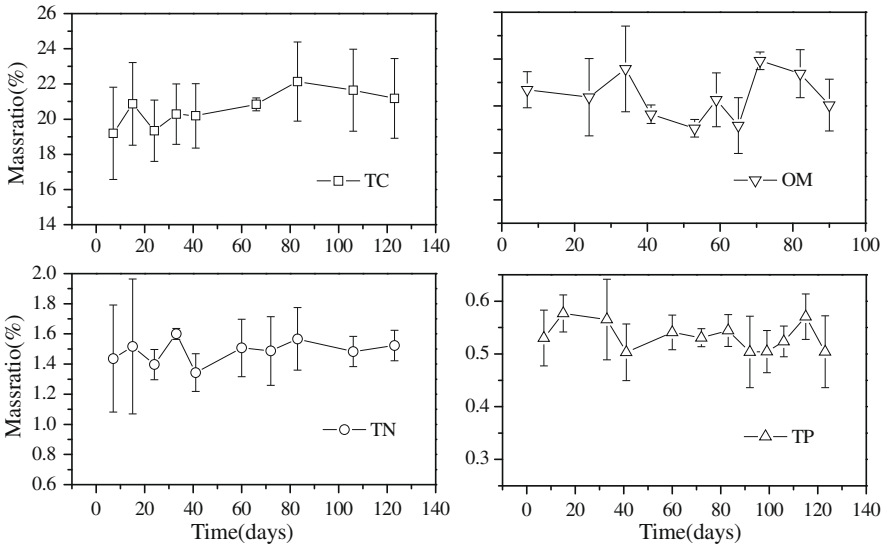

Fig. 5. Change of TC, TN, TP and OM in compost media during odor processing.

Table 5
The variation of soluble total nitrogen, soluble total phosphorous, NH_4^+–N and NO_3^-–N, unit/μg (g dry compost)$^{-1}$.

Properties	Soluble total phosphorous	Soluble total nitrogen	NO_4^+–N	NO_3^-–N
Initial	36.3 ± 2.4	966.6 ± 52.6	465.1 ± 37.8	376.3 ± 24.7
120 day	29.2 ± 3.7	1485.3 ± 131.4	677.2 ± 14.5	605.4 ± 46.2
140 day	26.4 ± 3.2	1396.5 ± 87.3	726.7 ± 62.5	663.5 ± 54.3

cess. Combined with the increase of NH_4^+–N content in compost media, the increase of pH could be attributed to sorption of ammonia. Anyway, the results demonstrated that acidification did not occur, which further justifies the use of compost-based biofilters for odor treatment.

The pressure drop was measured across compost biofilter during 140 days. The results show a variation in 30–40 mm H_2O m^{-1} (data not shown). Bibeau et al. (1997) indicated that even the pressure drop in the biofilter presented values of up to 60 mm H_2O m^{-1}, there were no compaction problems in the operation of the system. In our study, the increases of the pressure drop coincided with the addition of water to maintain the moisture of compost media. The experiment results herein indicated that there was no clogging of the biofilter during the whole processing.

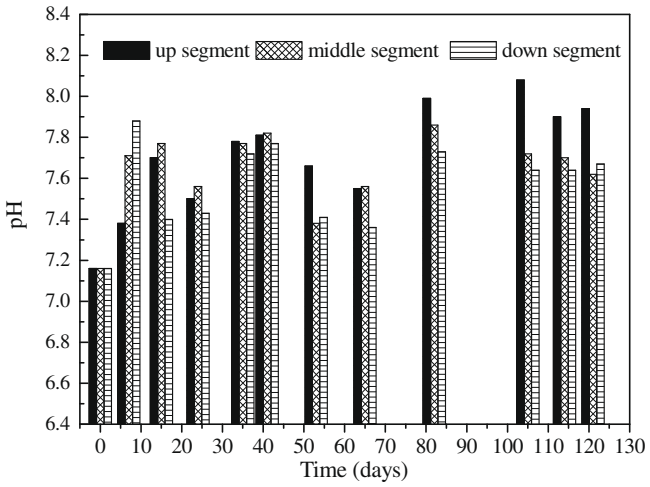

Fig. 6. Variation of pH of compost media during operation.

3.4. Biological properties of the compost media

The average colony count of samples from different segments was used to evaluate the microbial concentration because the value in the inlet layer is often higher than other layers (Wu et al., 2006). Fig. 7 shows the variations of the colony counts of various microorganisms in the filter media. The numbers of bacteria and molds increased with the operation from 2.7×10^7 and 1.7×10^7 cfu g^{-1} dry media to 1.0×10^8 and 5.7×10^7 cfu g^{-1} dry media, respectively. However, yeasts and actinomyces had an adverse trend, decreasing along with operation. The colony counts were respectively, 0.04 and 0.07 times of their initial values after 120 days of operation.

Bacteria are cited as the major microorganisms responsible for odor removal. According to Chuang (2007), strains of *Paracoccus denitrificans*, *Aminobacter aminovorans*, *Bacillus subtilis*, and *Pseudomonas putida*, which can degrade BTEX, sulphur- and nitrogen-containing compounds are abundant in the compost media of biofilters. Molds (filamentous fungi) such as the genus *Exophiala* are capable of degrading hydrophobic compounds and have been extensively studied in biofiltration systems for VOC treatment (e.g. Kennes and Veiga, 2004). Increase of bacteria and molds in this experiment potentially indicate that these groups are responsible for the observed VOC removal. Consequentially, the decrease in yeasts and actinomyces potentially indicates that they cannot utilize odorous compounds as the sources of energy. Incidentally, Sun et al. (2002) found the moisture content of packing material had influence on the growth of them.

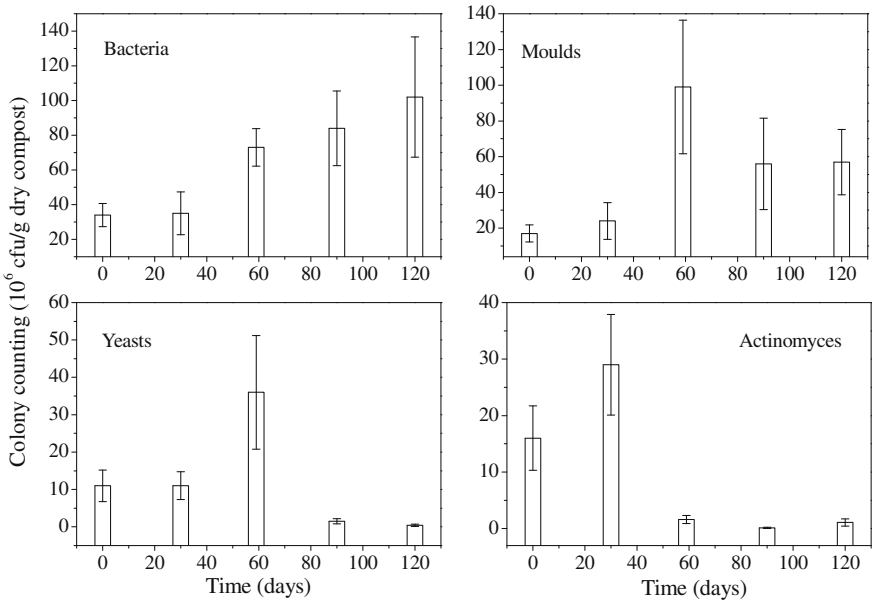

Fig. 7. Change of microbial communities in compost media along with biofilter operation.

4. Conclusions

(1) The components in odor during MSW BMT biostabilization process included BTEX, terpenes, alkane, alkene and sulphur compounds. Among 40 different chemical compounds identified in inlet of biofilter, the most prominent groups were alkylated benzenes, followed by alkanes, alkenes, terpenes and sulphur compounds. The compost biofilter showed remarkable removal ability for alkylated benzenes but poor performance for terpene.

(2) The variations of TVOC concentrations emitted from BMT biostabilization process had an obvious trend of gradually decreasing with the duration of the operation. TVOC concentrations in odors during biostabilization process period ranged from 0.7 to 87 ppmv, which showed an obvious trend of gradually decreasing with the duration of operation. The highest level of TVOC concentration appeared at early stages of processing. The experimental data demonstrated that removal efficiency of TVOC raised with the increase of EBRT, and the best results of 49.8–95% was obtained when the EBRT was 65 s.

(3) During 140 days, TN, TP, TC and OM in compost media did not change significantly throughout the biofiltration process. Ammonium nitrogen, nitrate nitrogen and soluble total nitrogen contents gradually increased with the odor treatment because of the sorption of ammonia from the odor stream. However, soluble total phosphorous in packing bed decreased by 27.3%. For the consideration of long-term operation, phosphorous should be supplemented periodically.

(4) There were obvious changes in the numbers of various microorganisms. Bacteria and molds increased with the operation, but yeasts and actinomyces decreased gradually, their colony counts were 3.7, 3.4, 0.04 and 0.07 times of their initial values, respectively.

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