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Evaluation of pilot-scale in-vessel composting for food waste treatment

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Abstract

This study is aimed to evaluate the performance of pilot-scale in-vessel composting for food wastes treatment. The composting plant was installed with 324 m^3 of the composting bay volume and 14,000 kg/day of the composting material flow rate. The evaluations studied included the operational indices, the compost maturity indices, and the quality of the final compost. Blowers of this system were useful in maintaining aerobic condition (over 6% oxygen concentration in off-gas) through the entire compost bay. The levels of indices evaluated remained constant in the final part of composting. The final compost was satisfactory for its agricultural application. It was revealed in this study that bulk density bore a linear relation to moisture content during composting, and the final compost without bulking agent showed negative correlation between heavy metal and organic matters content.

Keywords: In-vessel composting; Food waste; Composting evaluation

1. Introduction

The disposal of food waste is rapidly becoming one of the major unsolved problems in Korea. More than 22% of the municipal solid wastes has been reported to be food wastes, of which generation was 0.24 kg/cap·day in 2004 [1]. When food wastes are disposed of in landfill site without any pretreatment, they cause problems such as leachate and odor. In 2005, Korean government regulated food waste not to be disposed directly of in landfill. This situation has urged the need to develop and study alternative technologies to control food wastes in Korea.

Composting has emerged as an attractive option for treating food wastes due to less environmental pollution and beneficial use of the final product [2–5]. Composting is the biological decomposition and stabilization of organic substrates under the condition of thermophilic temperatures as a result of biologically produced heat [6]. Two types of composting system have been widely applied: in-vessel systems and window systems. The in-vessel composting system has advantages over the window system: it requires less space and provides better control than windows; it involves a high process efficiency [7]. Thus, food wastes have been successfully composted for those purposes [8].

This study has been conducted to evaluate the performance of a pilot-scale in-vessel composting plant. This plant was first built in the Nanji Landfill site, Korea, for investigating the potential to compost food wastes generated from Seoul Metropolitan City. The evaluations are focused on operational indices during composting in the composting bay, compost maturity indices and the quality of the final compost.

2. Materials and methods

2.1. Operating conditions in the composting plant

A schematic diagram of the pilot-scale in-vessel composting plant evaluated in this study is illustrated in Fig. 1. The system

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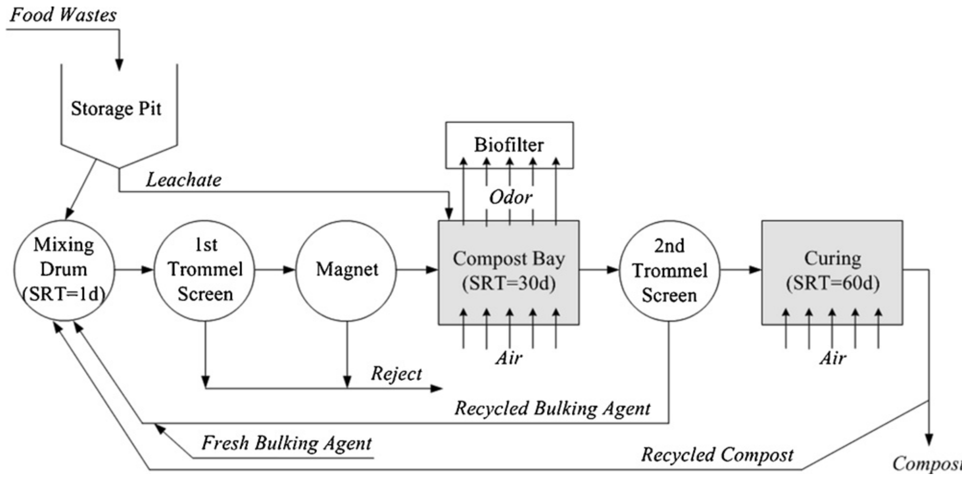

Fig. 1. Schematic diagram of pilot-scale in-vessel composting plant.

had continuous horizontal flows. Wood chips generated from old furniture were mixed with food wastes as bulking agent in a mixing drum. The mixing ratio of bulking agent to food waste was four to three on a wet weight basis. The flow rate of the mixing materials was 14,000 kg/day. A trommel screen having a diameter of 1.5 m and a length of 5 m was installed in order to separate materials sized over 5 cm. A magnetic separation system was equipped and operated if ferrous materials were contained in the flows. A compost bay with 45 m length, 6 m width, and 1.2 m depth (a total volume of 324 m^3) was used. Using the conveyor, the mixture of food waste and bulking agent was moved at a rate of 1.5 m/day through the compost bay, in which solid retention time (SRT) was 30 days. Forced aeration at a rate of 0.15 m^3/m^3 min was supplied to maintain adequate oxygen level and temperature inside the compost pile. The second trommel screen having screen size of 4.75 mm was installed in order to separate bulking agent. The separated bulking agent was reintroduced into the mixing drum. The mixing ratio of the recycled bulking agent and the fresh one was 1–3 on a volumetric basis. The compost produced was further stabilized in the curing pit during a period of 2 months. In order to treat odors from the system, a compost-packed biofilter was installed at the off-gas outlet, and operated in an upward flow mode. Food waste leachate generated from the storage pit was added at a rate of about 0.45 m^3/day within the first 20 m of the compost bay. The final compost was recycled as seeding materials, and mixed in the mixing drum. The mixing ratio of the recycled compost to food wastes was 0.1–1 on volumetric basis.

2.2. Materials

Physical and chemical characteristics of food wastes and bulking agent used in this study were provided in Table 1. The bulk density and the moisture content of food wastes were about 800 kg/m^3 and 80%, respectively. The moisture content of the feedstock was relatively high due to vegetables and fruit peels in food wastes. The initial C/N ratio of food wastes was 25. The bulking agent, of which bulking density and moisture content were 240 kg/m^3 and 10%, respectively, was used to provide moisture and porosity of feedstock.

2.3. Analytical methods

The moisture content of sample was measured after drying at 105 °C for overnight. The dried sample was ground and then used in analysis. The volatile solids (VS) were measured after igniting sample at 550 °C for 1 h. The water-soluble extract was prepared by the following procedure: 10 g of sample were first mixed with 100 ml of deionized water, then shaken for 2 h, and centrifuged at 3000 rpm. The supernatant was then filtered through a filter paper (Whatman No. 1). TOC (total organic carbon) and TKN (total Kjeldahl nitrogen) were measured by the Walkley Black method and semi-micro Kjeldahl method, respectively. pH and electrical conductivity were measured in the condition of solid-to-water mixture (weight:volume = 1:10). The E4/E6 ratio of optical adsorbance at 465 and 665 nm was determined from absorbance of 0.05 N $NaHCO_3$ solutions containing

Table 1
Physical and chemical properties of food waste and bulking agent

Item	Food waste	Bulking agent
Bulking density (kg/m^3)	800	240
Moisture content (%)	80	10
Conductivity (dS/m)	2.5	2.3
pH	4.4	7.3
VS (%, dry weight basis)	77	86
TOC (%, dry weight basis)	53	57
TKN (%, dry weight basis)	2.2	1.9
C/N ratio (dry weight basis)	25	30
Water-soluble TOC (%, dry weight basis)	1.2	0.07
Water-soluble TKN (%, dry weight basis)	0.043	0.014
Water-soluble C/N ratio (dry weight basis)	29	4
Heavy metal (mg/kg, dry weight basis)		
Pb	69	42
Zn	57	33
Cu	6	15
Ni	15	49
Cd	Not detected	5.6

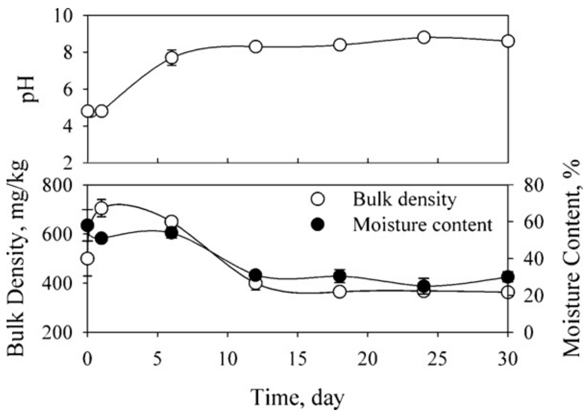

Fig. 2. Variations of bulk density, moisture content, and pH of the composting material within the compost bay. Note that SRT was 30 days.

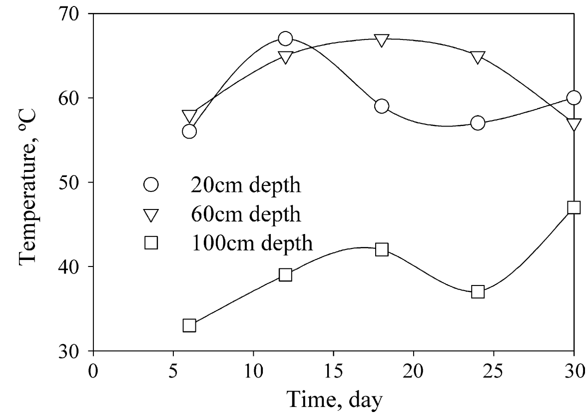

Fig. 4. Variation of temperature at the depth of 20, 60, and 100 cm from the top of the compost bay.

0.02% (w/v) samples [9]. Heavy metals of samples, which were digested by nitric and perchloric acids, were analyzed by an Atomic Absorption Flame Emission Spectrophotometer (Shimadzu 6501F, Japan). CO_2 and O_2 concentrations were measured by using a portable gas analyzer (GA94, Geotechnical Instrument Ltd., UK). A portable ammonia analyzer (Sensidyne, Japan) was used to measure NH_3 concentration. Temperature in the compost pile was measured using a portable thermometer. All analyses were triplicated in order to ensure reproducibility and representativeness of the sample.

3. Results and discussion

3.1. Operational indices

The operational indices were evaluated during a composting period of 30 days in the compost bay. They included bulk density, moisture content, pH, temperature, and off-gases. Fig. 2 shows the variations of pH, bulk density, and moisture content in the composting materials with time. The initial bulk density of the composting materials was relatively low. This might be due to lack of uniformly in the composting materials of food waste and bulk agent. Further to mixing in the composting bay after day 1, bulk density of the composting materials was 750 kg/m^3, and decreased to 390 kg/m^3 until day 12. Moisture content correspondingly decreased from 58% to 31%. After that, no significant changes in parameters have been observed.

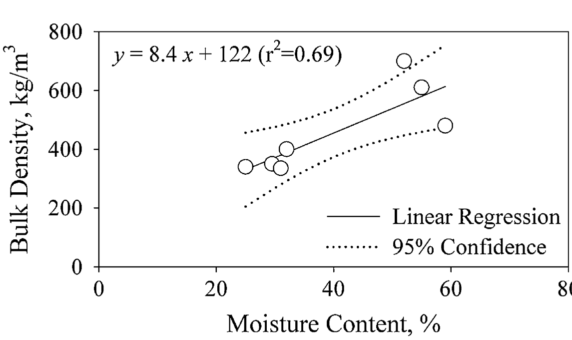

Fig. 3. Relationship between moisture content and bulk density during composting. The symbols presented represent the average experimental value.

Initial pH was as low as 5, mainly due to the low pH of food wastes as seen in Table 1. pH then increased to the level of 8.6 and remained constant. pH is a parameter which considerably affects the composting. It is believed that pH is optimized in the range between 6 and 7.5 for bacterial development [10]. Thus, Fig. 2 implies that decomposition of organic substrate was vigorous during the first 12 days, but it decreased after day 12. It is interesting to see in Fig. 3 that a linear relation between moisture content and bulk density was shown during composting. It is believed that bulk density decreases with increasing solids contents, i.e. decreasing water content [11].

Fig. 4 shows temperature variation along the depth of the bay. At the depths of 20 and 60 cm, temperature was maintained at 60 °C level. In contrast, temperature at the bottom (100 cm depth) was always lower than at other depths. Note that in this study, the aeration was designed to start when temperature became over 60 °C at the depth of 60 cm, and the aeration pipes were installed at the bottom. Since the entire composting materials have been allowed to tumble on the conveyer in the compost bay, no operational problems related with temperature have been observed during composting. Fig. 5 illustrates the variations of O_2, CO_2, and NH_3 concentrations in off-gas during composting. Measurements have been conducted at the middle depth (60 cm) of the bay. O_2 concentration was maintained over 12%, but 6% on day 12 (see Fig. 5). Correspondingly, the highest

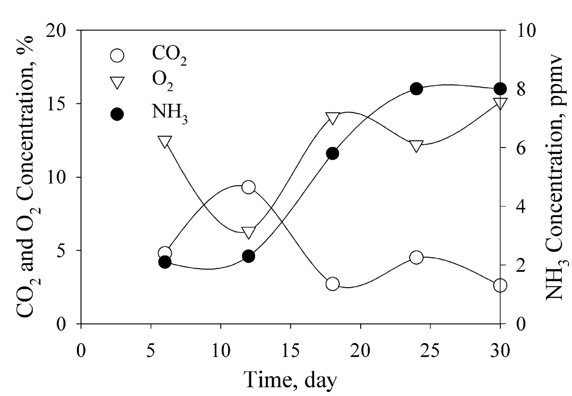

Fig. 5. Variations of CO_2, O_2, and NH_3 concentrations in off-gases during composting. The symbols presented represent the average experimental value.

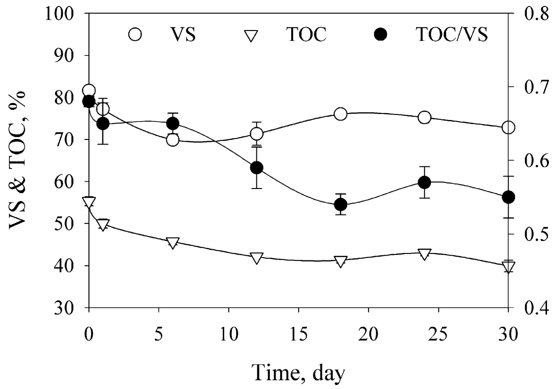

Fig. 6. Variations of VS and TOC during composting.

CO_2 concentration was observed on day 12. This demonstrated that the aeration of this composting system has provided enough air to aerobically decompose the organic substrates. 2 ppmv of NH_3 was detected until day 12 and increased up to approximately 8 ppmv at the end of the composting process. As a result of organic decomposition, NH_3 release increased with time. It is worthwhile to note that NH_3 released can be oxidized by the nitrification reaction, but the largest fraction probably lost from the compost by volatilization. It was proven by observing high temperature during composting (see Fig. 4).

3.2. Compost maturity

Compost maturity index is a very important parameter for compost production and application. Numerous maturity indices have been proposed, but no single method can be universally applied to all composts due to variation in feed stock and composting technology [12]. Organic matter, carbon-to-nitrogen ratio (C/N), and E4-to-E6 ratio were investigated as compost maturity indices in this study.

Fig. 6 shows the variation of organic matter content during composting. The variations of VS, TOC, and water-soluble TOC contents in VS (TOC/VS) were plotted with time. VS content in the composting material was initially 82%, and finally reduced to 73% at the end of the composting period of 30 days, implying 11% VS reduction. TOC content was initially 55%, and gradually decreased to 34%. This reduction (21%) was much higher than VS reduction (11%). The empirical relationship between VS and TOC of organic materials during composting could be expressed in TOC (%) = VS (%) × 0.56 [13,14]. In this study, the ratio of TOC to VS was initially 0.68, and decreased to 0.55.

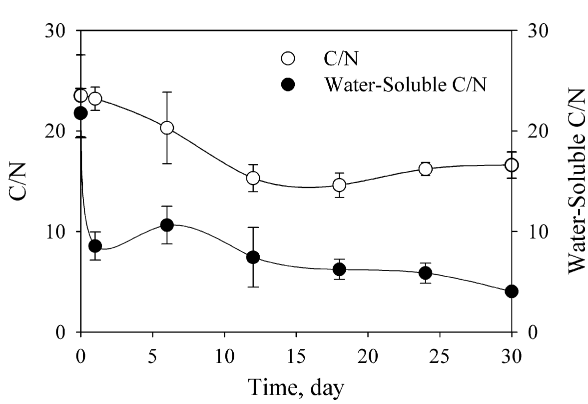

Fig. 7. Variations of C/N and water-soluble C/N ratios during composting.

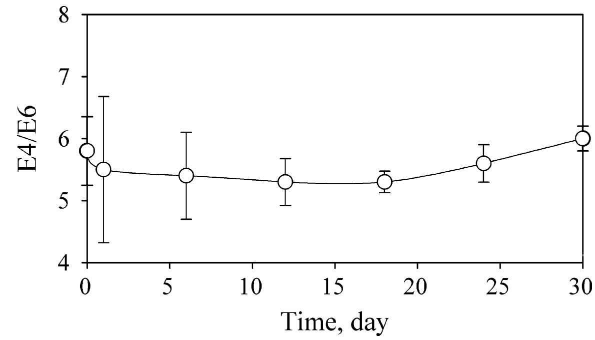

Fig. 8. Variation of E4/E6 during composting.

With respect to the nutritional needs for the microbial activity, C/N ratio of the composting material is the most important factor [11]. In composting, a large fraction of the carbon can be oxidized to carbon dioxide by metabolic activities. Nitrogen can be lost as ammonia-N. Fig. 7 shows the variation of C/N ratio with time. In this study, initial C/N ratio of the feed mixture was 24, and it rapidly dropped until day 12, implying that bioavailability of carbon was initially high. The C/N ratio then remained at the level of 17. Note that matured composts should ideally have a value of about 15 in order to avoid nitrogen immobilization when it will be applied to soil [15]. Shiralipour et al. [16] demonstrated that compost with C/N ratios greater than 30 may reduce crop production due to microbial immobilization. Indeed, Fig. 7 illustrates the variation of water-soluble C/N ratio with time. Water-soluble C/N ratio was dropped from 21.6 to 8.5 within 1 day. Water-soluble C/N ratio of the final compost was 4. The decrease in water-soluble C/N ratio was faster than that in solid C/N ratio. Erhart and Burian [15] reported that water-soluble C/N ratio ranged from 5.1 to 8.6 in the compost produced from household wastes. Avnimelech et al. [17] found that water-soluble C/N ratio started at 16 and dropped below 10 within a composting period of 30–40 days.

E4/E6 ratio, which shows the ratio of the humic acid and fulvic acid in the compost, is useful for evaluating maturity of compost as an assessment index for the molecular weight of humic substance [18–20]. E4/E6 ratios of the matured composts generally ranged from 7.7 to 9.1 [20]. In the study performed [21], E4/E6 slightly increased during the composting of municipal solid waste. In this study, E4/E6 varied at the early stage of composting, averaging between 5.3 and 5.6 as seen in Fig. 8. E4/E6 was finally 6.0 ± 0.2 on day 30. It is worthwhile to discuss that the formation of the oxygen functional groups in smaller molecules might result in the slight increase in E4/E6 parameter [21].

3.3. Compost quality

To evaluate the quality of the final compost, electrical conductivity as a salt content index and heavy metal content of the

Table 2
Physical and chemical properties of the compost produced in this study and the compost quality standards

Heavy metal (mg/kg, dry weight basis)	Compost of this study		Compost quality standard		
	Day 0	Day 30	Korea [27]	Washington State, USA [28]	British Columbia State, Canada [29]
Pb	28	40	150	150	150
Zn	125	203	–	1400	315
Cu	25	29	500	750	100
Ni	22	22	–	210	50
Cd	0.2	0.4	5	2	2.6

final compost produced were analyzed. Fig. 9 shows the variation of electrical conductivity with time. As seen in Fig. 9, the electrical conductivity slightly increased on day 1. Since decomposable compounds were easily released in the solution [22], the soluble ions in the water extract may increase slightly at the beginning of composting. Overall electrical conductivity was in the range of 2 to 3 dS/m during composting. Corti et al. [23] reported that the electrical conductivity of composts ranged between 0.14 and12.2 dS/m. In the study conducted in [15], mean electrical conductivity of biowaste composts was 2.3 dS/m. Avnimelech et al. [17] found that the electrical conductivity was initially 7.5 dS/m and dropped within a period of about 35 days to a stable level of about 4 dS/m.

Table 2 illustrates initial and final heavy metal concentrations in the compost with bulking agent, of which results were compared with the compost quality standard. The concentrations of heavy metals studied increased after composting. This observation might be due to the concurrent decrease in the organic matter content of the composting materials. Especially, Zn concentration of the compost increased from 124 to 203 mg/kg on a dry weight basis, corresponding to a 64% increase. Similar observations were made by others: a 25–40% increase of Zn content in composting of spent pig litter [24]; 15–36% in composting of cattle manure [22]; 50–100% in composting of municipal solid wastes [25]; and 150% in composting of separated swine manure [26]. This stabilized compost can be finally considered to be very satisfactory for its agricultural use.

Note that bulking agent applied had relatively high concentrations of heavy metals as seen in Table 1. For ensuring the relation between organic matter decomposition and heavy metal content, the compost separated with bulking agent was analyzed, of which results were found in Table 3. Correlation coefficients were obtained by using SPSS program. From the results of the correlation test, a negative correlation was established for all heavy metals tested with the TOC and VS content in compost.

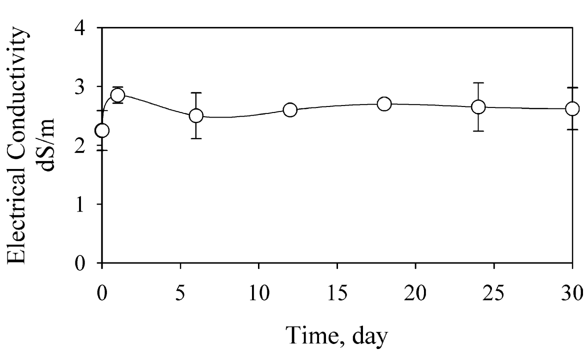

Fig. 9. Variation of electrical conductivity during composting.

Table 3
Correlation coefficients (r) between parameters

	Pb	Zn	Cu	Ni	Cd	TOC	VS
Compost without bulking agent							
Pb	1.00						
Zn	0.95**	1.00					
Cu	0.57	0.69	1.00				
Ni	0.67	0.74*	0.57	1.00			
Cd	0.76*	0.86**	0.74*	0.62	1.00		
TOC	−0.65**	−0.93**	−0.80	−0.83*	−0.75**	1.00	
VS	−0.80**	−0.95**	−0.94	−0.89*	−0.81**	0.92**	1.00

* Significant at 0.05 probability levels.
** Significant at 0.01 probability levels.

4. Conclusions

Performance of pilot-scale in-vessel composting for food wastes treatment was evaluated in this study. This study was first to generate effluent publishing data for composting food wastes generated from Seoul Metropolitan City, Korea, that was detailed enough for use by design engineers. Specific conclusions that can be drawn from this study include the following:

1. As the operational indices, bulk density, moisture content, pH, temperature, and off-gases were useful in evaluating the composting performance. When high CO_2 concentration was generated, high temperature and high oxygen consumption rate were found, revealing vigorous microbial activity. Bulk density and moisture content then decreased.
2. Compost maturity was evaluated by using the following indices: TOC and VS of organic matter, C/N and E4/E6. The levels of indices were relatively stable in the latter part of the composting period, and they remained constant.
3. The final compost produced in this study was satisfactory for its agricultural application in terms of electrical conductivity as a salt content index and heavy metal contents. Linear correlation analysis for the compost without bulking agent showed that negative correlations existed between heavy metal contents and organic matters.

References

[1] Ministry of Environment, Environmental statistics yearbook, Ministry of Environment Republic of Korea, Gwacheon, Korea, 2006.

[2] C. Filippi, S. Bedini, R. Levi-Minzi, R. Cardelli, A. Saviozzi, Cocomposting of olive oil mill by-products: chemical and microbiological evaluation, Compost Sci. Util. 10 (2002) 63–71.
[3] K.C. Das, E.W. Tollner, M.A. Eiteman, Comparison of synthetic and natural bulking agents in food waste composting, Compost Sci. Util. 11 (2003) 27–35.
[4] M. Benito, A. Masaguer, A. Moliner, R.D. Antonio, Chemical and physical properties of pruning waste compost and their seasonal variability, Bioresour. Technol. 97 (2006) 2071–2076.
[5] B. Zenjari, H. El Hajjouji, G. Ait Baddi, J.R. Bailly, J.C. Revel, A. Nejmeddine, M. Hafidi, Eliminating toxic compounds by composting olive mill wastewater–straw mixtures, J. Hazard. Mater. 138 (2006) 433–437.
[6] S.R. Iyengar, P.P. Bhave, In-vessel composting of household wastes, Waste Manage. 26 (2006) 1070–1080.
[7] D. Cekmecelioglu, A. Demirci, R.E. Graves, N.H. Davitt, Applicability of optimized in-vessel food waste composting for window system, Biosyst. Eng. 91 (2005) 479–486.
[8] J.I. Chang, J.J. Tsai, K.H. Wu, Thermophilic composting of food waste, Bioresour. Technol. 97 (2006) 116–122.
[9] V. Chanyasak, M. Hirai, H. Kubota, Changes of chemical components and nitrogen transformation in water extracts during composting of garbage, J. Ferment. Technol. 60 (1982) 439–446.
[10] A.A. Zorpas, E. Kapetanios, G.A. Zorpas, P. Karlis, A. Vlyssides, I. Haralambous, M. Loizidou, Compost produced from organic fraction of municipal solid waste, primary stabilized sewage sludge and natural zeolite, J. Hazard. Mater. 77 (2000) 149–159.
[11] R.T. Haug, The Practical Handbook of Compost Engineering, CRC Press, Inc., Boca Raton, FL, 1993.
[12] X.T. He, T.J. Logan, S.J. Traina, Physical and chemical characteristics of selected U.S. municipal solid waste composts, J. Environ. Qual. 24 (1995) 543–552.
[13] G.M. Savage, L.L. Eggerth, C.G. Golueke, Composting and Recycling Municipal Solid Waste, Lewis Publishers, Boca Raton, FL, 1993.
[14] K.S. Ro, K.T. Preston, S. Seiden, M.A. Bergs, Remediation composting process principles: focus on soils contaminated with explosive compounds, Environ. Sci. Technol. 28 (1998) 253–282.
[15] E. Erhart, K. Burian, Evaluating quality and suppressiveness of Austrian biowaste composts, Compost Sci. Util. 5 (1997) 15–24.
[16] A. Shiralipour, D.B. McConnell, W.H. Smith, Physical and chemical properties of soils as affected by municipal solid waste compost application, Biomass Bioenergy 3 (1992) 261–266.
[17] Y. Avnimelech, M. Bruner, I. Ezrony, R. Sela, M. Kochba, Stability indexes for municipal solid waste compost, Compost Sci. Util. 4 (1996) 13–20.
[18] A.N. Daygamie, D. Isfan, Chemical and biological change in composting of wood shavings, sawdust and peat moss, Can. J. Soil Sci. 41 (1991).
[19] C. Garcia, T. Hernandez, F. Costa, Study on water extract of sewage sludge composts, Soil Sci. Plant Nutr. 37 (1991) 399–408.
[20] H. Dinel, M. Schnitzer, S. Dumintet, Compost maturity: chemical characteristics of extractable lipids, Compost Sci. Util. 4 (1996) 16–25.
[21] M. Jerzykiewicz, J. Drozd, A. Jezierski, Organic radicals and paramagnetic metal complexes in municipal solid waste composts. An EPR and chemical study, Chemosphere 39 (1999) 253–268.
[22] Y. Inbar, Y. Hadar, Y. Chen, Recycling of cattle manure: the composting process and characterization of maturity, J. Environ. Qual. 22 (1993) 857–863.
[23] C. Corti, L. Crippa, P.L. Genevini, M. Centemero, Compost use in plant nurseries: hydrological and physicochemical characteristics, Compost Sci. Util. 6 (1998) 35–45.
[24] S.M. Tiquia, N.F.Y. Tam, I.J. Hodgkiss, Composting of spent pig litter at different seasonal temperatures in subtropical climate, Environ. Pollut. 98 (1997) 97–104.
[25] L. Leita, M. De Nobili, Water-soluble fractions of heavy metals during composting of municipal solid waste, J. Environ. Qual. 20 (1991) 73–78.
[26] J.H. Hsu, S.L. Lo, Effect of composting on characterization and leaching of copper, manganese, and zinc from swine manure, Environ. Pollut. 114 (2001) 119–127.
[27] W. Namkoong, N.S. Lee, J.S. Park, B.H. In, J.M. Hur, J.A. Park, Operating characteristics of composting facility during composting of food waste and co-composting of food waste and sewage sludge, Korean J. Environ. Health 28 (2002) 86–92 (in Korean).
[28] Cal Recovery System, Compost classification/quality standards for the state of Washington. State of Washington Department of Ecology, Washington, 1990.
[29] British Columbia, Waste management act: production and use of compost regulation. British Columbia Regulation 334/93. November 19, 1993, p. 15.