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Biofiltration of Ammonia Gas from Composting Using Sawdust as Biofilter Media

퇴비화 암모니아 가스의 톱밥 바이오 필터 매체에 의한 생물학적 탈취

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Abstract

Dairy manure amended with crop and forest residues (moisture 69% wet basis, C/N 22) was composted in a 605 L pilot-scale vessel using continuous air flow (56 L/min) for 19 days. Three pilot-scale sawdust biofilters (moisture 63%, pH 5.0) were built to clean biological waste gas from the composting process. For each methods, two replicated experiments were monitored over a period of three weeks. The system was evaluated to determine the biofilter media depth that would be adequate for compost odour reduction. The compost air cleaning was measured based on ammonia gas concentration before and after passing through the biofilter. Ammonia gas removal efficiency over 3 weeks was 42, 75 and 87% at sawdust biofilter media depth levels of 202, 400 and 600 mm, respectively. Each sawdust biofilter was operated at a moisture content in the range of 60~62% (wb), a temperature from 15 to 25℃, an average pressure drop from 240 to 340 Pa and a detention time from 60 to 180 seconds during the biofiltration process.

Keywords : Biofiltration, Ammonia gas, Composting, sawdust

I. Introduction

Biofilters have been used as a means to treat odorous compounds and potential air pollutants from biological waste gas streams. In recent years, the interest and use of biofilters for odour control in composting facilities has increased dramatically. Biofilters have successfully ope-rated using materials such as soils, composts, shredded bark, wood chips, volcanic ash or a mixture of these (Williams and Miller, 1993; Epstein, 1997).

As odorous or contaminated gases are passed through this medium, two basic removal me-chanisms occur simultaneously: they are ab-

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sorption/adsorption and biooxidation (Naylor et al., 1988). As odorous gases and aerosols pass through a biofilter, they are adsorbed on the surfaces of the biofilter medium particles and/or absorbed into the moist surface layer (water film) of these particles (Eitner, 1984; Lesson and Winer, 1991; Williams and Miller, 1992).

Ammonia gases from composting or livestock facilities are collected and transported to a biofilter by way of a blower and ventilation system. Uniform air distribution is critical in biofilter designs to prevent channeling of exhaust gases through the biofilter media (Janni and Nicolai, 2000). Hong et al. (2001) found that wood chip biofilters operated most efficiently at a media depth in the range of 400 to 600 mm for ammonia removal from composting of manure. The average ammonia removal rate varied from 79% to 82%. Hong et al. (2000) reported that a stabilized hog manure compost biofilter removed 61 to 82% of the ammonia emission from the continuous and intermittent aeration composting process. In order for a biofilter to operate efficiently, the biofilter medium must meet several requirements including moisture content (50 ~ 70% wb), residence time (120 ~ 180s), temperature (15 ~ 35℃), pH (6 ~ 9), pressure drop (<400Pa), media depth (400 ~ 600 mm) and gas flow rates (0.78 ~ 1.2 m^3/h) through biofilters (Janni and Nicolai, 2000; Hong et al, 2001; Clark and Wnorowski, 1992; Toffey, 1997; Rands et al., 1981).

The objective of this research was to evaluate the effect of sawdust biofilter media depth on ammonia gas removal rate during dairy manure composting in a closed system.

Ⅱ. Materials and Methods

For this study, the experimental treatment examined the effects of biofiltration of ammonia from a composting process. Pilot-scale composting was done in a 605 L reactor (1,080 mm in diameter and 660 mm in depth). This reactor vessel was built from a circular PVC barrel that had 50 mm of polystyrene insulation around the side wall, base and cap to reduce heat loss. Three biofilter vessels were constructed from a metallic cylinder that was insulated with polystyrene. Each vessel was approximately 1,000 mm in height and 300 mm in diameter. A perforated galvanized steel grate formed a plenum at the vessel's base to distribute exhaust gas from the compost reactor uniformly through the biofilter. Three experimental sawdust biofilter media depths of 200, 400 and 600 mm (Biofilter A, B and C, respectively) were used to test the effect of biofilter depth on the biofiltration process. A schematic diagram of the blower, compost reactor, and three biofilter vessels is shown in Fig. 1. The blower provided air to the compost reactor through a 40 mm (ID) PVC pipe that was equipped with an orifice plate. The pressure drop across the biofilter media was measured daily using a manometer for each vessel.

For the continuous air flow, a fan provided 56 L/min (3.36 m^3/h or 0.6 L/min.kg.dm) airflow for aeration of the compost. Exhaust gases were distributed into four ways, three of which were connected to the biofilters and one of which was connected to the boric acid flask to measure the ammonia emission before filtering. Compost exhaust gas flow rate through each biofilter

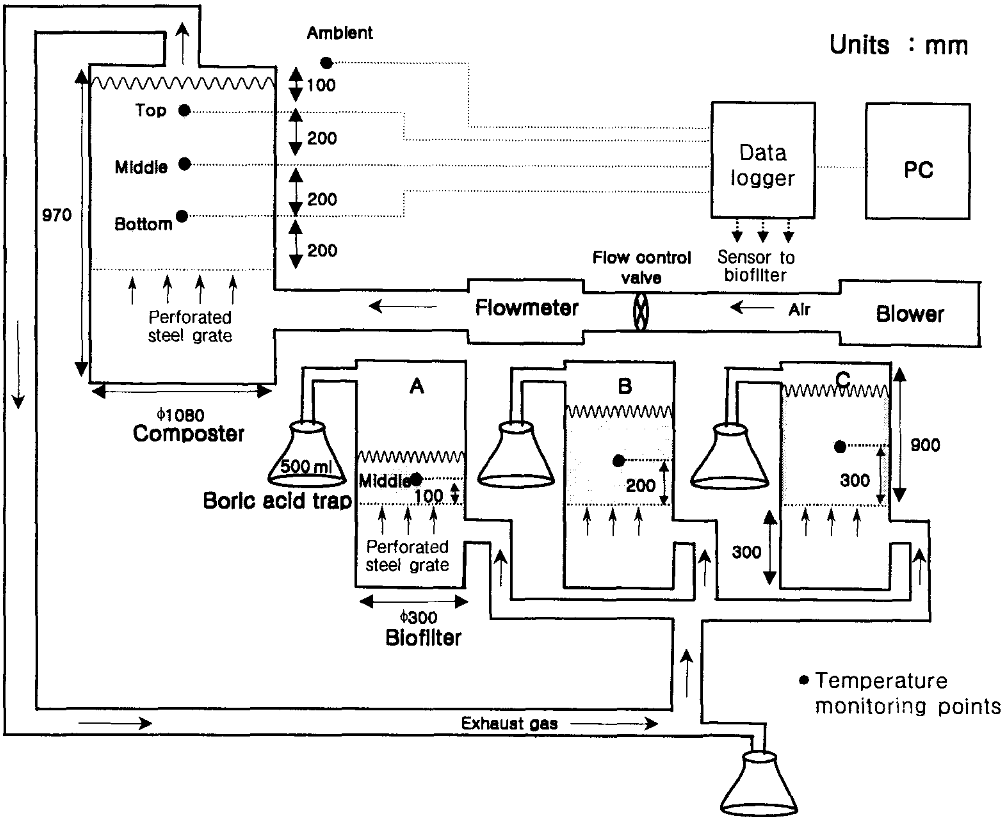

Fig. 1 Schematic of compost exhaust gas flow and temperature monitoring points for biofilter system

media was approximately 14 L/min assuming that the exhaust gases were divided into four ways equally. This study was conducted using continuous aeration to closely approximate field scale units.

Fresh dairy manure was collected from a dairy housing unit at the experimental station for animal husbandry of the Sunchon National University and mixed with soy sludge, rice hulls and sawdust using shovels on a concrete floor. The mixing ratios adjusted the moisture content of the mixtures to 65 to 70 % wb and a C/N of 20~25. The compost reactor received a mixture of dairy manure, soy sludge, rice hulls and sawdust in the wet weight ratio of 10 : 1 : 1 : 1. The run lasted for the active composting period of 19 days and no mixing was done during the composting and biofiltration process. Approximately 0.8 kg samples were collected from six arbitrarily selected points for each compost and biofilter vessel at the start and at the end of each run. The samples were analyzed for moisture content (MC), pH, density, ash, electrical conductivity (EC), mass, total nitrogen (T-N), total carbon (T-C) and C/N ratio by the standard methods for soil chemical properties (RDA, 1988). All analyses were carried out in duplicate.

Type−K thermocouples were inserted into the compost reactor at the top, middle, and bottom and into the middle of the biofilter media in each vessel (Fig. 1). Temperature readings were recorded for each vessel every hour using a data logger (21X, Campbell Scientific) and a personal computer.

Ammonia concentrations of exhaust gas from the composting reactor and biofilter vessels were obtained once a day using boric acid traps and titration with hydrochloric acid (Hong et al., 1998). Traps were changed approximately every 24 hours. Statistical analysis of data was done using analysis of variance (ANOVA). For evaluation of results, an α =0.05 was selected for identifying significant differences.

The ammonia removal rates were determined by:

$$R = \frac{I-O}{I} \times 100\ (\%) \qquad (1)$$

where, R = gas removal rate (%),
I = inlet gas concentration (ppm),
O = outlet gas concentration (ppm).

Ⅲ. Results and Discussion

The properties of dairy manure, soy sludge, rice hulls and sawdust are shown in Table 1. The raw dairy manure had a C/N ratio of 20.0 and MC of 80.5% (wb). To adjust these parameters, manure was mixed with soy sludge, rice hulls, and sawdust. The main reason for choosing soy sludge as the bulking agent was its availability of high EC, low pH, and relatively small particle size with high biodegradability.

Tables 2 and 3 show the mean values for the physicochemical composition of the compost

Table 1 Physicochemical properties of feedstock materials used in compost mixes

Items	Dairy Manure	Soy Sludge	Rice Hulls	Sawdust
MC (%, db)	80.50	60.04	8.50	10.00
T-C (%, db)	42.74	50.68	39.64	47.58
T-N (%, db)	2.14	5.71	0.49	0.11
C/N (-)	20.0	5.9	80.9	432.5
pH (-)	6.3	4.9	6.3	5.1
Ash (%, db)	2.44	5.10	14.52	0.40
EC (mS/cm)	3.57	15.00	0.40	0.21
Density (kg/m^3)	101	701	92	170
Mass (kg)	260	26	26	26

Table 2 Initial and final physicochemical properties of compost mixture

Properties	MC (%, db)	T-C (%, db)	T-N (%, db)	C/N (-)	pH (-)	Ash (%, db)	EC (mS/cm)	Density (kg/m^3)	Mass (kg)
Initial	68.91	43.52	1.94	22.4	6.3	3.55	4.67	467	317
Final*	66.20	42.04	2.06	20.4	7.4	4.15	3.55	342	269

* Final values were measured after 19 days of composting.

Table 3 Initial and final physicochemical properties of sawdust biofilter

Properties		MC (%, db)	T-C (%, db)	T-N (%, db)	C/N (-)	pH (-)	Ash (%, db)	EC (mS/cm)	Density (kg/m^3)
Initial		62.78	47.47	0.09	527.4	4.9	0.01	0.18	210
Final*	A (200 mm)	60.19	46.35	0.22	210.7	5.0	0.01	0.12	200
	B (400 mm)	61.46	46.61	0.23	202.7	5.0	0.27	0.18	193
	C (600 mm)	62.15	47.11	0.20	235.6	4.8	0.01	0.18	216

* Final values were measured after 19 days of filtration.

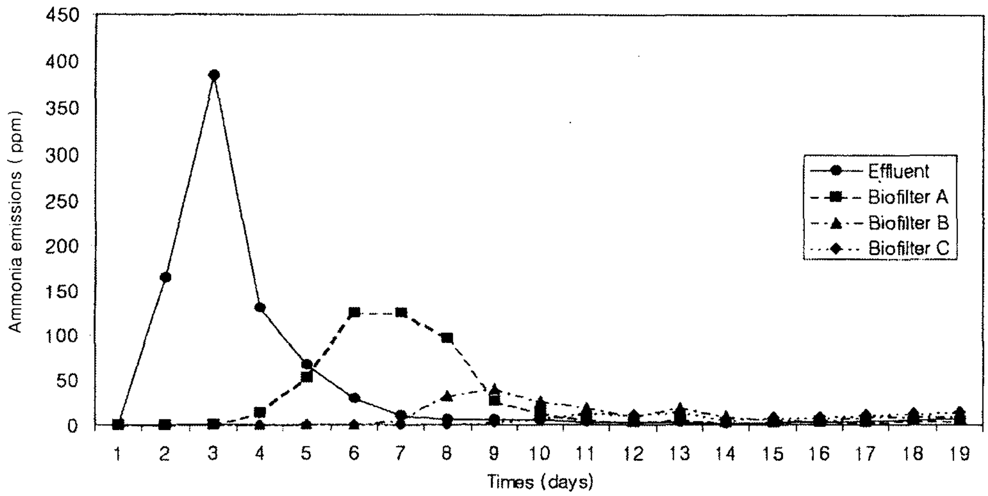

Fig. 2 Graphical records of daily ammonia concentrations during composting and biofiltration process

mixtures for composting and sawdust for biofiltration before and after the composting/biofiltration process, respectively. In this study, the initial C/N ratio and MC of the raw compost were 22.4 and 68.9 %, respectively. The density, EC, mass, T−C and C/N ratio decreased as the raw mixture was composted, while pH, ash and T−N increased. The C/N ratio dropped from an initial value of 22.4 to the value of 20.4. The pH increased from an initial value of 6.3 to the value of 7.4. The MC did not change significantly throughout the composting process.

Water was supplied to the sawdust and mixed manually to use as a biofilter medium and the physicochemical properties of the biofilter medium were measured. The initial MC, pH and T−C of the raw sawdust biofilter were 62.8% (wb), 4.9 and 47.47, respectively. The change in MC, pH and T−C were quite small and the C/N ratio dropped from an initial value of 527.4 to final values ranging from 202.7 to 235.6 during the biofiltration process. Measured T−N content increased from an initial value of 0.09% (db) to values of 0.20 ~ 0.23% (db) at the end of the process.

Ammonia gas concentrations occurred during the first week of composting as shown in Fig. 2. Ammonia gas concentrations for the composting process reached a peak of 384 ppm on the 3rd day. However, the highest ammonia gas concentrations during the biofiltration process was 125 ppm for biofilter A on the 6th day, 40 ppm for biofilter B on the 9th day and 15 ppm for biofilter C on the 13th day, respectively. Maximum allowable ammonia gas concentration was reported by Esmay and Dixon (1986) and Midwest Plan Service (1985) to be 50 ppm. These results therefore suggest that, during composting/biofiltration, a suitable sawdust biofilter depth in a closed system would be between 400 and 600 mm.

Cumulative ammonia emissions during composting and biofiltration are shown in Fig. 3. Cumulative ammonia emissiond were 12,739 mg for composting and 7,396 mg, 3,204 mg and 1,681 mg for biofilters A, B and C during biofiltration, respectively. These results indicate treatments B and C would give lower emissions than A. The sawdust biofilter removed 42%, 75% and 87% of the ammonia emitted from decomposition vessels A, B and C, respectively in a 19-day period.

The time variation of top, middle, and bottom temperature in the compost and the middle temperature in each biofilter vessel during the composting/biofiltration process are shown in Fig. 4 and Fig. 5. The temperature in the compost reactor reached the thermophilic composting stage (>40℃) within one to two days after aeration began. Top temperature of the compost reached this range more rapidly. Condensed water of about 5,500 mL was generated from the exhaust pipe during composting process. The airflow rate to the compost was changed from 0.6 to 0.4 L/min.kg.dm at the 10th day to control the composting temperature. Airflow reduction slightly increased the temperature in compost without higher ammonia gas emission during composting. Biofiltration temperatures in the middle of biofilters A, B and C varied from 15 to 25℃ according to the ambient temperature.

Results for treatments A, B and C gave average

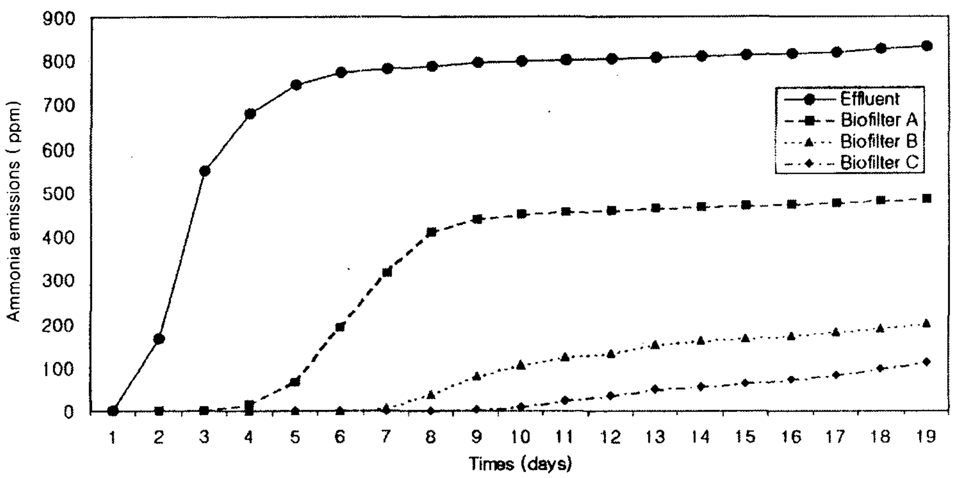

Fig. 3 Comparison of cumulative ammonia concentrations for effluent gas from composting and biofiltration process

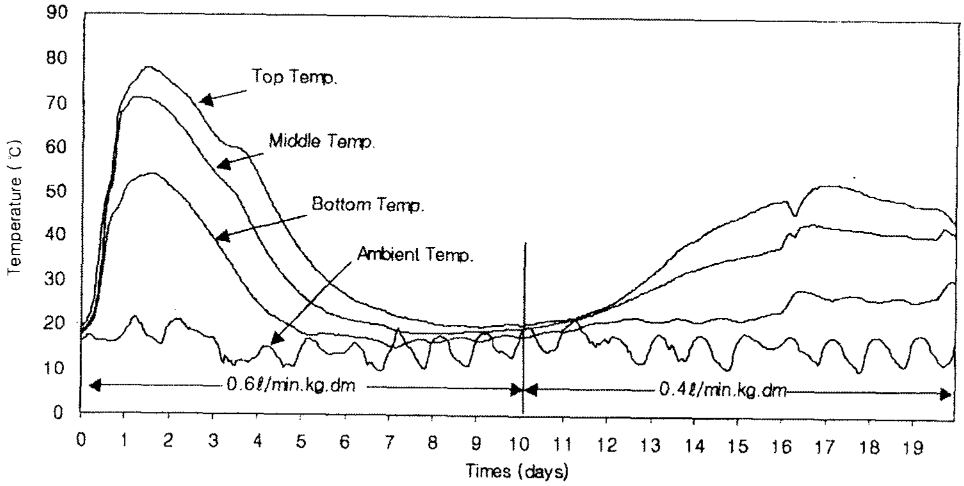

Fig. 4 Graphical records of daily compost and ambient temperatures during composting

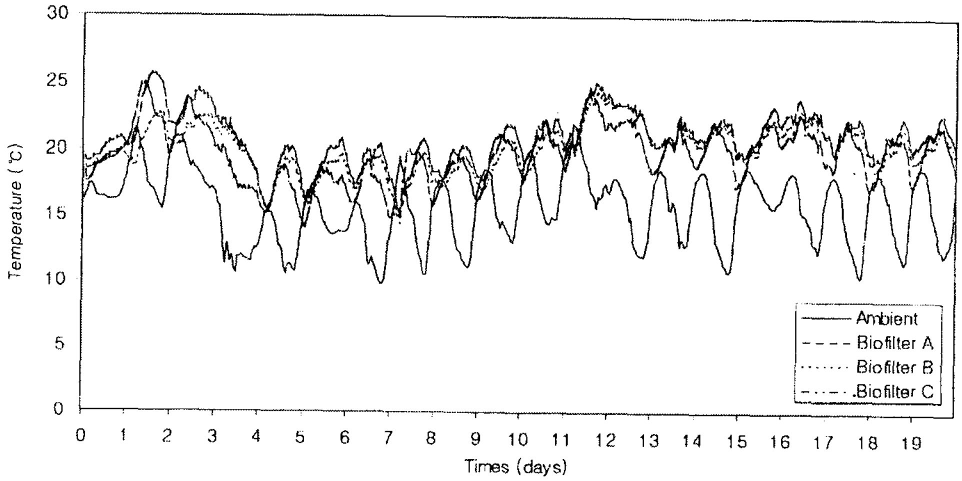

Fig. 5 Graphical records of daily biofilter and ambient temperatures during biofiltration

pressure drop of 338, 302 and 236 Pa during the biofiltration process, respectively. Differences in biofilter pressure drop in working system are influenced by the biofilter homogeneity (Classen et al., 2000). Detention times of 61, 121 and 182 seconds were calculated for biofilter A, B and C, respectively, using the flowrate (0.6L/min.kg.dm) of supplied air, dimension of biofilter and the depth of biofilter materials.

Ⅳ. Conclusions

Results showed ammonia gas concentrations for the composting process reached a peak of 384 ppm on the 3rd day. Ammonia concentrations after biofiltration process dropped to below maximum allowable concentrations of 50 ppm for both media depth 400 and 600 mm. Biofilter media depth is important to both minimize the emissions of ammonia and the pressure drop across the media for compost odour control. Recommended media depth for sawdust biofilters ranged from 400 to 600 mm for about 80% reduction in ammonia emission from composting. This depth provided a detention time in the range of 120 to 180 seconds with an average pressure drop between 300 and 240 Pa.

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