

## Short Communication

Size distributions of total airborne particles and bioaerosols  
in a municipal composting facility

Jeong Hoon Byeon, Chul Woo Park, Ki Young Yoon, Jae Hong Park, Jungho Hwang \*

*School of Mechanical Engineering, Yonsei University, Seoul 120-749, Republic of Korea*

Received 18 July 2007; received in revised form 5 September 2007; accepted 7 September 2007

Available online 22 October 2007

**Abstract**

Size distributions of total airborne particles and bioaerosols were measured in a full-scale composting facility, using an optical particle counter and an agar-inserted six-stage impactor, respectively. Higher concentrations of total airborne particles and bioaerosols were detected at a sampling location near the screening process preceded by the composting process than at sampling locations in the composting process. At the sampling location near the screening process, the concentrations of total airborne particles were approximately  $10^8$  particles/m<sup>3</sup> at the size of 0.3  $\mu\text{m}$  and  $10^5$  particles/m<sup>3</sup> at 6.2  $\mu\text{m}$ . The concentration of bioaerosols was about  $10^4$  CFU/m<sup>3</sup> in each stage of  $\geq 7.0$   $\mu\text{m}$  (1st stage), 7.0–4.7  $\mu\text{m}$  (2nd), 4.7–3.3  $\mu\text{m}$  (3rd), 3.3–2.1  $\mu\text{m}$  (4th), 2.1–1.1  $\mu\text{m}$  (5th) and 1.1–0.65  $\mu\text{m}$  (6th). Most of sub-micron particles smaller than 1  $\mu\text{m}$  among the total airborne particles were believed to originate from the ambient air.

© 2007 Elsevier Ltd. All rights reserved.

**Keywords:** Size distribution; Total airborne particles; Bioaerosols; Composting facility

**1. Introduction**

The process of waste decomposition in composting facilities releases a variety of airborne particles, including bioaerosols (Folmsbee and Strevett, 1999; Laine et al., 1999; Prasad et al., 2004; Taha et al., 2005). In fact, a large proportion of municipal waste is subject to rot, and is readily colonized by both bacteria and fungi (Liang et al., 2006; Kader et al., 2007). Upon the handling of such wastes, these bacteria and fungi can be aerosolized (i.e., form bioaerosols), and may present infectious, allergenic, or toxic hazards (Lavoie et al., 2006). In a previous report, Folmsbee and Strevett (1999) determined the total concentrations of bacteria, fungi, and actinomycetes at a composting facility. Laine et al. (1999) and Tolvanen and Hänninen (2005) measured the mass concentrations of total airborne particles and colony-forming unit (CFU) bioaerosol concentration. Although the size distributions of both total airborne

particles and bioaerosols are crucial for the design of optimal dust emission control devices in composting facilities, no relevant data are currently available on the subject. In this study, number concentrations of total airborne particles and bioaerosols as a function of particle size were measured at a full-scale municipal composting facility, using an optical particle counter and an agar-inserted six-stage impactor, respectively.

**2. Experimental**

This study was conducted at a full-scale composting facility in Incheon City, Korea, with a treatment capacity of 24 tons of food waste per day. The composting processes took place in an industrial warehouse-type composting facility, with occasional turning over a 15-day period. The compost piles were then stored in a static state for an additional 20–25 days.

Air temperature–relative humidity, ammonia concentration, and total odors were measured using a thermo-hygrometer (Testo 605, Testo AG, Germany), a real-time

\* Corresponding author. Tel.: +82 2 2123 2821; fax: +82 2 312 2821.  
E-mail address: [hwangjh@yonsei.ac.kr](mailto:hwangjh@yonsei.ac.kr) (J. Hwang).

ammonia monitor (Porta Sens II, Ati, USA), and an odor level indicator (OMX-SR, Shinyei, Japan), respectively. The measured data were consistent with those previously reported by Pagans et al. (2006) and Schlegelmilch et al. (2005), who performed their measurements in a lab-scale and a full-scale composting facility, respectively. Air velocity was also assessed using an air velocity meter (VELOCICHECK, TSI, USA). Distributions of air velocity, temperature, and humidity are shown in Fig. 1. The air flow patterns were the consequence of heat convection, originating from the temperature gradient between the area surrounding the compost and the areas near the stacks. The suction in the area near the stacks, as well as the outdoor air coming into the facility at a temperature of 19.7 °C, also influenced the patterns of air flow. As shown in Fig. 1, air sampling was conducted along these locations on day 5, day 10, and day 15 of the composting process (20 m, 35 m, and 50 m from the entrance of food waste, respectively). The other sampling site was located 3 m away from the right-side end of the compost screener. A continuous feed conveyor transported the compost to the screener, which then centrifugally separated unwanted materials from the compost. The compost falling through the screener was then directed toward the compost piles.

At each of the sampling locations, the averaged size distributions of total airborne particles were measured over a 2-min period (interval time: 6 s) using an optical particle

counter (OPC, Model 1.108, Grimm Technology, Germany). The OPC operates on the basis of optical light scattering, by which each single particle can be sized and counted. The sample flow is fixed at a rate of 1.2 L/min and is maintained by an internal flow controller. The air sample, which harbors various differently sized particles, is constantly drawn via a volume-controlled pump through a flat beam of light generated by a focused laser diode. Each scattered signal generated by the disruption of this beam is then detected using a high-speed photodiode. The signals are then analyzed by an integrated pulse height analyzer, and are classified into one of 15 different size ranges and counted. The smallest particle detectable by the OPC system is 0.3  $\mu\text{m}$ . In order to determine the size distributions of bioaerosols, a six-stage impactor (TE-10-800, Tisch Environmental, USA) was employed at each of the sampling sites. The use of this instrument made it possible to divide the bioaerosols into six fractions, in accordance with their aerodynamic diameters, as follows:  $\geq 7.0 \mu\text{m}$  (1st stage), 7.0–4.7  $\mu\text{m}$  (2nd), 4.7–3.3  $\mu\text{m}$  (3rd), 3.3–2.1  $\mu\text{m}$  (4th), 2.1–1.1  $\mu\text{m}$  (5th) and 1.1–0.65  $\mu\text{m}$  (6th). A plastic Petri dish (diameter 9 cm) containing agar was utilized as the impacting plate for each stage of the impactor. Trypticasesoy agar (TSA), malt extract agar (MEA), and half-strength nutrient agar were utilized to sample bacteria, fungi, and actinomycetes, respectively (Folmsbee and Strevett, 1999; Górný et al., 1999; Laine et al., 1999; Taha

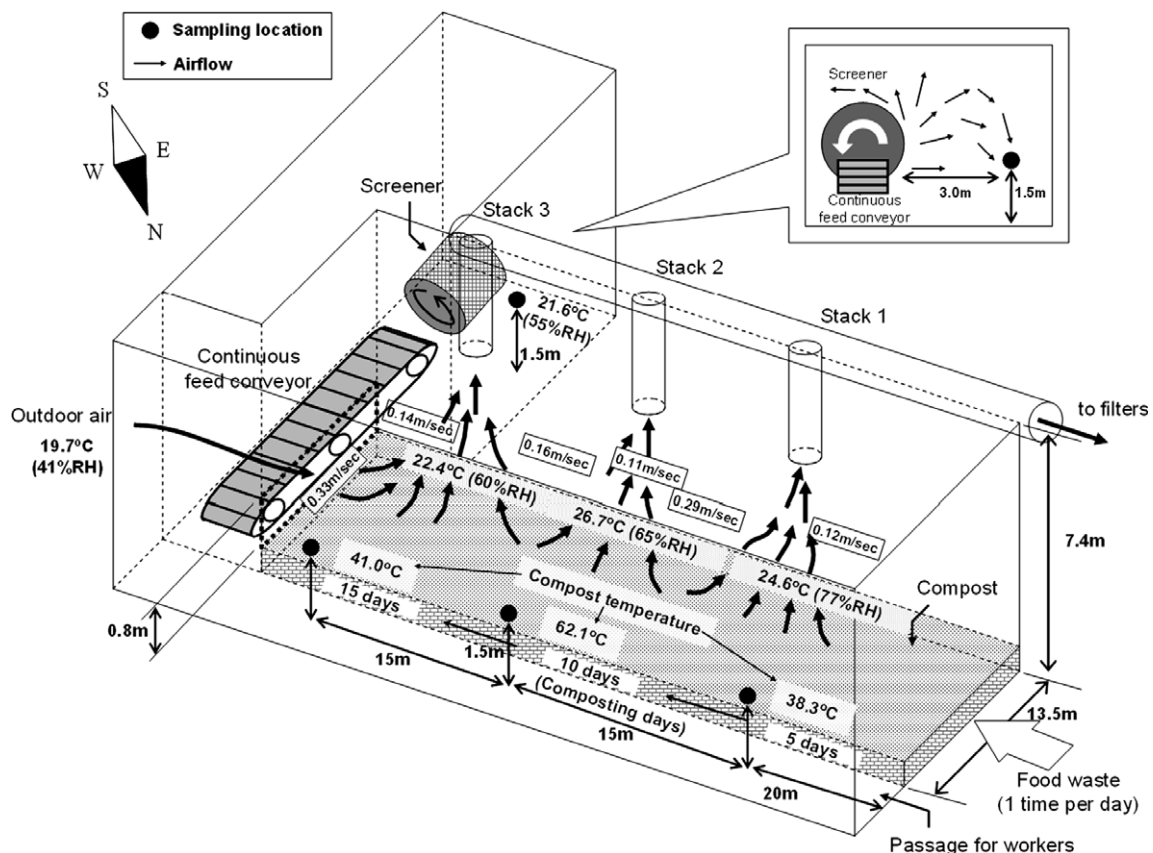


Fig. 1. Layouts of the composting facility and air flow conditions.

et al., 2005, 2006). These agars were prepared via the dissolution of specific quantities of agar powders (40.0 g, 33.6 g, and 23 g for TSA, MEA, and half-strength nutrient agar) in 1 L of deionized water, followed by sterilization in an autoclave under a gauge pressure of 0.1 MPa at a temperature of 121 °C. The air was sampled with a vacuum pump at a constant 28.3 L/min flow rate. Sampling times for bacteria, fungi, and actinomycetes were 1 min, 4 min, and 4 min, respectively (Folmsbee and Streve, 1999). Once the required air had been drawn through, the six plates were covered and incubated. The TSA plates were then incubated for 5 days at 30 °C, and the MEA and half-strength nutrient agar plates were incubated for 7 days at 30 °C and 40 °C, respectively (Folmsbee and Streve, 1999; Tolvanen and Hänninen, 2005). Finally, the numbers of colonies were counted after each incubation period, and the bioaerosol concentrations were expressed in terms of colony-forming units (CFU) per unit volume of air. The OPC and impactor were operated simultaneously at each sampling location. The sampling was repeated four times at each sampling location.

The collected air samples were identified by the Korean Culture Center of Microorganisms. The bacterial isolates were gram-stained and identified using the API kit (bio-Mérieux Co.) and the BIOLOG Microstation System. The isolates were stored as water suspensions at ambient temperature prior to use. The cellular fatty acid compositions of the fungi and actinomycetes were analyzed via gas chromatography (GC, 6890 series, Agilent, USA). The retention time of each of the peaks was compared with that of the standard sample. The sizes of identified microorganisms were obtained according to the reports of Holt et al. (1994) and Willeke et al. (1996). Then each size,  $d_e$ , was converted to aerodynamic diameter,  $d_a$ , via the equation given below (Hinds, 1998):

$$d_a = d_e \left( \frac{\rho_p}{\rho_0 \chi} \right)^{1/2} \quad (1)$$

in which  $\rho_p$  is the density of the microorganism (kg/m<sup>3</sup>),  $\rho_0$  is the standard density (1000 kg/m<sup>3</sup>), and  $\chi$  is the dynamic shape factor.

### 3. Results and discussion

Fig. 2 shows the size distributions of the total airborne particles and bioaerosols sampled at the four aforementioned locations. It appears that the concentrations of total particles and bioaerosols were highly dependent on screening, as the screening operation might readily cause any particles or microorganisms to suspend in the air. In the case of total airborne particles, the concentrations were approximately  $1.0 \times 10^8$  #/m<sup>3</sup> at the diameter of 0.3 µm, but were drastically decreased as increasing the particle diameter. Most of these highly concentrated submicron particles were believed to originate from ambient air, since ambient air contains much higher concentration of submicron particles

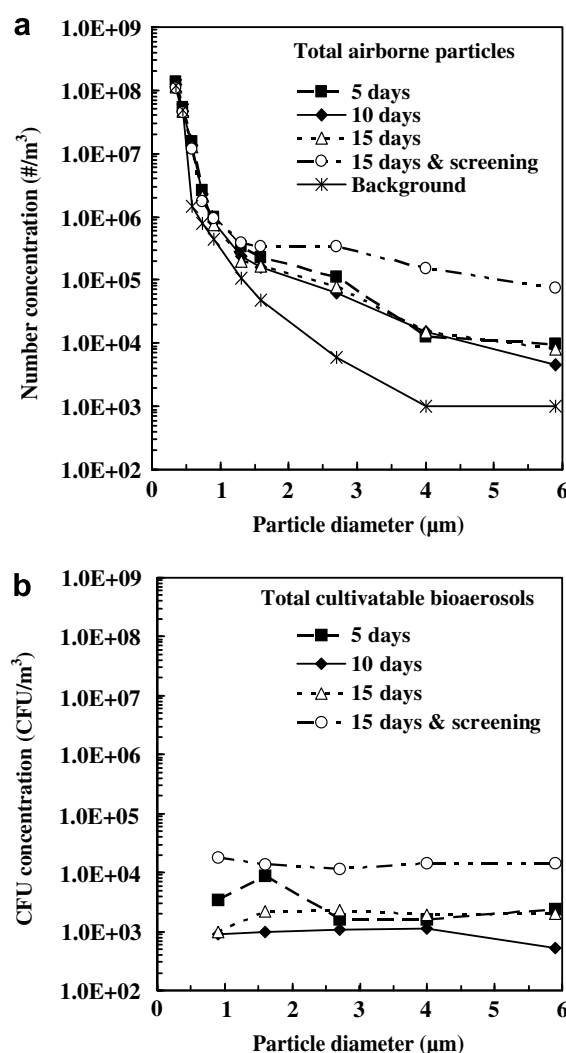


Fig. 2. Size distributions of (a) total airborne particles and (b) total cultivatable bioaerosols.

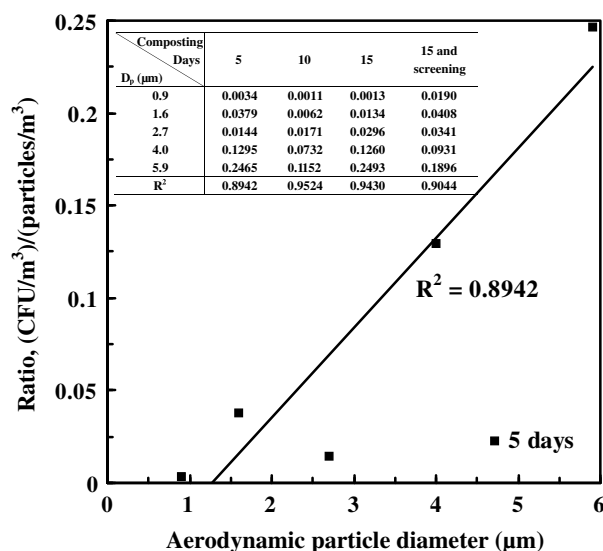


Fig. 3. Ratio of total airborne particles and bioaerosols.

Table 1  
Species distributions in the sampled air (5 days of composting)

Microorganism	Stage (size range, $\mu\text{m}$ )	Species identified
Bacteria (85.1%)	6th (0.65–1.1)	<i>Bacillus amyloliquefaciens</i> , <i>Bacillus cereus</i> 2
	5th (1.1–2.1)	<i>Bacillus amyloliquefaciens</i> , <i>Bacillus cereus</i> 2, <i>Staphylococcus lentus</i>
	4th (2.1–3.3)	<i>Bacillus amyloliquefaciens</i> , <i>Bacillus cereus</i> 2, <i>Staphylococcus lentus</i> , <i>Staphylococcus xylosus</i>
	3rd (3.3–4.7)	<i>Bacillus amyloliquefaciens</i> , <i>Bacillus cereus</i> 2, <i>Staphylococcus lentus</i> , <i>Staphylococcus xylosus</i>
	2nd (4.7–7.0)	<i>Bacillus amyloliquefaciens</i> , <i>Bacillus cereus</i> 2, <i>Staphylococcus lentus</i> , <i>Staphylococcus xylosus</i>
	1st ( $\geq 7.0$ )	<i>Bacillus amyloliquefaciens</i> , <i>Bacillus cereus</i> 2, <i>Staphylococcus lentus</i> , <i>Staphylococcus xylosus</i> , <i>Bacillus mycoides</i> , <i>Ochrobactrum anthropi</i>
Fungi (0.3%)	6th (0.65–1.1)	<i>Pseudallescheria boydii</i> , <i>Aspergillus fumigatus</i>
	5th (1.1–2.1)	<i>Pseudallescheria boydii</i> , <i>Aspergillus fumigatus</i>
	4th (2.1–3.3)	<i>Pseudallescheria boydii</i> , <i>Aspergillus fumigatus</i> , <i>Chaetomium</i> spp., <i>Penicillium</i>
	3rd (3.3–4.7)	<i>Pseudallescheria boydii</i> , <i>Aspergillus fumigatus</i> , <i>Chaetomium</i> spp.
	2nd (4.7–7.0)	<i>Pseudallescheria boydii</i>
	1st ( $\geq 7.0$ )	<i>Pseudallescheria boydii</i>
Actinomycetes (14.6%)	All sizes ( $\geq 0.65$ )	<i>Streptomyces rochei</i>

than micrometer particles, as shown in Fig. 2a and previous studies (Kim et al., 2007; Lin et al., 2007). Unlike the total airborne particles, bioaerosol concentration did not show any significant relations with their sizes. Interestingly, the airflow patterns shown in Fig. 1 exerted a profound effect on bioaerosol concentrations at each of the sampling locations. The higher numbers obtained at day 5 of the composting process compared to those obtained at day 10 and day 15 might be attributed to the higher flow rate of air, which harbored a considerable quantity of microorganisms, toward stack 1. Although a convective airflow was also detected near stack 3, the data obtained at day 15 of the composting process was lower than that obtained at day 5 of the composting process, as the bioaerosols were diluted by the outdoor air near stack 3.

Fig. 3 shows the ratio between the bioaerosols and total airborne particles, measured at day 5 of the composting process. For particles smaller than  $1\mu\text{m}$ , the ratio was nearly zero due to high concentration of total airborne particles. The ratio increased directly with increasing particle size. However, at even the highest ratio of 0.249 at the diameter of  $5.9\mu\text{m}$ , it was implied that the majority of the total airborne particles was composed of non-biological, biological but not-viable, or viable but not-cultivable matters. The ratios for other sampling locations are shown in the inset table of Fig. 3.

Table 1 shows the microbial species sampled by the impactor. The percentages of bacteria, fungi, and actinomycetes were 85.1%, 0.3%, and 14.6%, respectively. Table 1 also shows the identification results of sampled bioaerosols. According to the reports of Holt et al. (1994) and Willeke et al. (1996), aerodynamic diameters of *Bacillus*, *Staphylococcus*, and *Streptomyces* were 0.5–2.5  $\mu\text{m}$ , 0.5–1.5  $\mu\text{m}$ , and 0.5–2.0  $\mu\text{m}$ , respectively. However, Table 1 shows that the aerodynamic diameters of the microorganisms detected by the impactor ( $\geq 0.65\mu\text{m}$ ,  $\geq 1.1\mu\text{m}$ ,  $\geq 0.65\mu\text{m}$ ) for *Bacillus*, *Staphylococcus*, and *Streptomyces*, respectively, were somewhat larger than those reported

previously by Holt et al. (1994) and Willeke et al. (1996). One of the reasons for this may be that the majority of bioaerosols within the composting facility was suspended as agglomerates (bioaerosols with certain dust particles and/or other bioaerosols). Górný et al. (1999) and Wittmaack et al. (2005) reported that microorganisms in these environments could occur as single cells or as aggregates of cells, as well as fragments of bacterial cells, spores of bacilli, actinomycetes and fungi, portions of actinomycetal and fungal hyphae, endotoxins, exotoxins, enzymes, glucans, mycotoxins, or as conglomerations with small dust particles, as well as in combination with droplets of water or saliva droplets, or so-called “nuclei droplets”.

#### 4. Conclusions

Higher concentrations of total airborne particles and bioaerosols were detected at a sampling location near the screening process preceded by the composting process than at sampling locations in the composting process. At the sampling location near the screening process, the concentrations of total airborne particles were approximately  $10^8$  particles/ $\text{m}^3$  at the size of  $0.3\mu\text{m}$  and  $10^5$  particles/ $\text{m}^3$  at  $6.2\mu\text{m}$ . The concentration of bioaerosols was about  $10^4$  CFU/ $\text{m}^3$  in each stage of  $\geq 7.0\mu\text{m}$  (1st stage), 7.0–4.7  $\mu\text{m}$  (2nd), 4.7–3.3  $\mu\text{m}$  (3rd), 3.3–2.1  $\mu\text{m}$  (4th), 2.1–1.1  $\mu\text{m}$  (5th) and 1.1–0.65  $\mu\text{m}$  (6th). Most of submicron particles smaller than  $1\mu\text{m}$  among the total airborne particles were believed to originate from the ambient air. Controlling the total airborne particles and bioaerosols in composting facilities is necessary for the safety and health of workers and local residential environment. Emission characteristics determined in this study can be a useful information for establishing the proper control measure in composting facilities. Moreover, optimizing flow rate or arrangement of ventilation on composting process would be proposed for an effective emission control.

## Acknowledgement

This work was supported by Grant No. 2006-8-0183 from the Agricultural Specified Research Project of the Rural Development Administration.

## References

- Folmsbee, M., Strevett, K.A., 1999. Bioaerosol concentration at an outdoor composting center. *Journal of the Air and Waste Management Association* 49, 554–561.
- Górny, R.L., Dutkiewicz, J., Krysińska-Traczyk, E., 1999. Size distribution of bacterial and fungi bioaerosols in indoor air. *Annals of Agricultural and Environmental Medicine* 6, 105–113.
- Hinds, W.C., 1998. *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles*. John Wiley & Sons, Inc., New York, NY, pp. 53–55.
- Holt, J.G., Krieg, N.R., Sneath, P.H.A., Staley, J.T., Williams, S.T., 1994. *Bergey's manual of determinative bacteriology*. Lippincott Williams & Wilkins, Baltimore, MD, pp. 532–668.
- Kader, N.A.E., Robin, P., Paillat, J.M., Leterme, P., 2007. Turning, composting, and the addition of water as factors affecting gaseous emissions in farm manure composting. *Bioresource Technology* 98, 2619–2628.
- Kim, J., Jung, C.H., Choi, B.C., Oh, S.N., Brechtel, F.J., Yoon, S.C., Kim, S.W., 2007. Number size distribution of atmospheric aerosols during ACE-Asia dust and precipitation events. *Atmospheric Environment* 41, 4841–4855.
- Laine, M.M., Jørgensen, K.S., Kiviranta, H., Vartianinen, T., Jokela, J.K., Adibi, A., Salkinoja-Salonen, M., 1999. Bioaerosols and particles release during composting of contaminated sawmill soil. *Bioremediation Journal* 3, 47–58.
- Lavoie, J., Dunkerley, C.J., Kosatsky, T., Dufresne, A., 2006. Exposure to aerosolized bacteria and fungi among collectors of commercial, mixed residential, recyclable and compostable waste. *Science of the Total Environment* 370, 23–28.
- Liang, Y., Leonard, J.J., Fedes, J.J.R., McGill, W.B., 2006. Influence of carbon and buffer amendment on ammonia volatilization in composting. *Bioresource Technology* 97, 748–761.
- Lin, P., Hu, M., Wu, Z., Niu, Y., Zhu, T., 2007. Marine aerosol size distributions in the springtime over China adjacent seas. *Atmospheric Environment* 41, 6784–6796.
- Pagans, E., Barrena, R., Font, X., Sánchez, A., 2006. Ammonia emissions from the composting of different organic wastes. Dependency on process temperature. *Chemosphere* 62, 1534–1542.
- Prasad, M., Werf, P., Brinkmann, A., 2004. Bioaerosols and composting – a literature evaluation. *Composting Association of Ireland Teo*, 2004.
- Schlegelmilch, M., Streese, J., Biedermann, W., Herold, T., Stegmann, R., 2005. Odour control at biowaste composting facilities. *Waste Management* 25, 917–927.
- Taha, M.P.M., Pollard, S.J.T., Sarkar, U., Longhurst, P., 2005. Estimating fugitive bioaerosol releases from static compost windrows: feasibility of a portable wind tunnel approach. *Waste Management* 25, 445–450.
- Taha, M.P.M., Drew, G.H., Longhurst, P.J., Smith, R., Pollard, S.J.T., 2006. Bioaerosol releases from compost facilities: evaluating passive and active source terms at a green waste facility for improved risk assessments. *Atmospheric Environment* 40, 1159–1169.
- Tolvanen, O.K., Hänninen, K.I., 2005. Occupational hygiene in a waste incineration plant. *Waste Management* 25, 519–529.
- Willeke, K., Ulevicius, V., Reponen, T., Grinshipun, S.A., 1996. Development and evaluation of aerosol generators for biological materials. *Journal of Aerosol Science* 27, S249–S250.
- Wittmaack, K., Wehnes, H., Heinzmann, U., Agerer, R., 2005. An overview on bioaerosols viewed by scanning electron microscopy. *Science of the Total Environment* 346, 244–255.