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Monitoring of Bioaerosol Emission from a Sludge Composting Facility

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Abstract: This paper presents results of one-year monitoring of bioaerosol dispersion from a full-scale sludge composting facility in the east coast of the USA. By using two-stage Andersen air samplers with a sequential sampling procedure developed in this study, a total of 24 sets of bioaerosol samples were collected on petri dishes for plate counting. The sampling program utilized a computer air dispersion model (ISCST) to predict the downwind distance at the maximum concentration. Field samplings were performed at upwind, onsite, and predicted downwind locations. The results of this study conclude that the 95% confidence intervals estimated for the background concentrations were: 75-173 cfu/m^3 for aerobic bacteria, 262-706 cfu/m^3 for mesophilic fungi, 5.0-14 cfu/m^3 for thermophilic fungi, and 2.3-12 cfu/m^3 for *Aspergillus fumigatus*. The maximum probably downwind concentrations were evidently increased for aerobic bacteria and thermophilic fungi, but not for mesophilic fungi, fecal coliform, and fecal streptococcus. The zone of influence was estimated to be in the range of 1500-1800 m from the composting facility. Particles smaller than 8 μm constituted 40% of aerobic bacteria and 70-75% of fungi, which may be inhaled into the lung and cause the hypersensitive effect in the respiration system.

Keywords: bioaerosol; compost; air dispersion model; *Aspergillus fumigatus*.

1. Introduction

The easurement of airborne microorganisms has gained continuing interests for that many bioaerosols found in indoor and outdoor environments cause adverse effects to human health. These working environments of concern include composting plants [1,2], cotton factories [3], swine confinement buildings [4,5], grain elevators and farms [6,7]. Exposure levels in these environments were substantially higher than those found in indoor environments with no obvious sources of microbial contamination. The exposure concentrations may be as high as 10^5-10^9 colony-forming units per cubic meter (cfu/m^3), while the indoor concentrations seldom exceed 10^4 cfu/m^3 [8].

Composting is a process of aerobic stabilization of organic matters and the aeration causes dispersion of microbial particles. Depending on the type of feedstock, the bioaerosol contains various types of virus, bacterium and parasite. Kothary et al. (1984) found that the microbial density of screened compost was as high as 10^6 cfu/gm [2]. The highest counts (2000-4000 cfu/m^3) of *Aspergillus fumigatus* in air were detected at 1

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meter downwind from the compost piles and the concentration decreased to 200-1000 cfu/m^3 at 50 meter downwind. Clark et al. (1983) also found that more than 50% of Gram-negative bacteria and *Aspergillus fumigatus* were detected as the respiratory particle sizes at four composting plants[1]. This demonstrates that the contribution of airborne microorganisms from composting facilities could be significant.

As a result of aerobic reaction, composting is characterized by the generation of heat resulting from microbial activity. The temperature normally increases up to 50-60 ^oC and the heat will destroy most of the microorganisms. However, high temperatures during composting favor the growth of thermo-tolerant actinomycetes and fungi [9,10]. Some of these organisms are known as secondary pathogens, particularly *Aspergillus fumigatus* [11]. Inhalation of *Aspergillus fumigatus* can cause hypersensitivity to sensitized individuals. In addition, inhalation can cause colonizing and invasive infections in the lung for individuals weakened by age, other diseases, or deficient immunological response. The diseases caused by *Aspergillus fumigatus* are referred to as "aspergillosis". The maladies include extrinsic asthma, extrinsic allergic alveolitis, allergic bronchopulmonary aspergillosis and invasive aspergillosis etc [11].

Jones and Cookson (1983) investigated the background microbial air quality prior to the operation of the composting site [12]. This paper presents the results of the follow-up monitoring after the startup of the composting facility. While these data are just recently released, it is valuable to document the kind of data generated from the long-term field study. Four types of viable airborne microorganisms (aerobic bacteria, mesophilic fungi, thermophilic fungi and *Aspergillus fumigatus*) were investigated using a two-stage Andersen air sampler technique from May 1990 to April 1991. A sequential sampling scheme based on the time of the airborne particles traveling between two locations was developed in this study. The sampling procedure utilized a computer air dispersion model to predict the downwind distance of the maximum concentrations at various wind speeds. The purpose of this study was to investigate whether the concentration levels of airborne microorganism were elevated from the background (upwind) concentrations and attributable to the sludge composting operation.

2. Materials and methods

2.1. Compost plant

The composting plant was located on the east coast of the USA. As shown in Figure 1, the study area was a suburban area with moderate to heavy residential and commercial activities. The facility utilized an extended aerated static pile (EASP) process to compost a mixture of undigested primary and secondary sludge, which was predewatered by vacuum filters using lime and ferric chloride for conditioning. The design capacity of this composting facility was 600 wet tons per day (wtpd) for sludges containing 18 ~ 20 % solids with a 70 % volatile content. A capacity of 400 wtpd at 22 % solids was actually designed and operated.

The dewatered sludge was delivered to the facility and mixed with wood chips. The mixed sludge was then placed on a wood-chip bed for active composting for 20 days, followed by pre-screen drying for 5 days. Wood chips were then screened from the sludge at the completion of active composting. The stabilized sludge was retained for 30 days for further curing after screening. Vacuum aeration occurred from the piping structures at active composting, prescreen drying, and screening processes, which were the areas responsible for major bioaerosol dispersion. The onsite monitoring station chosen in this study was beneath the pad

fans, located on the roof of the building complex for active composting and pre-screen drying.

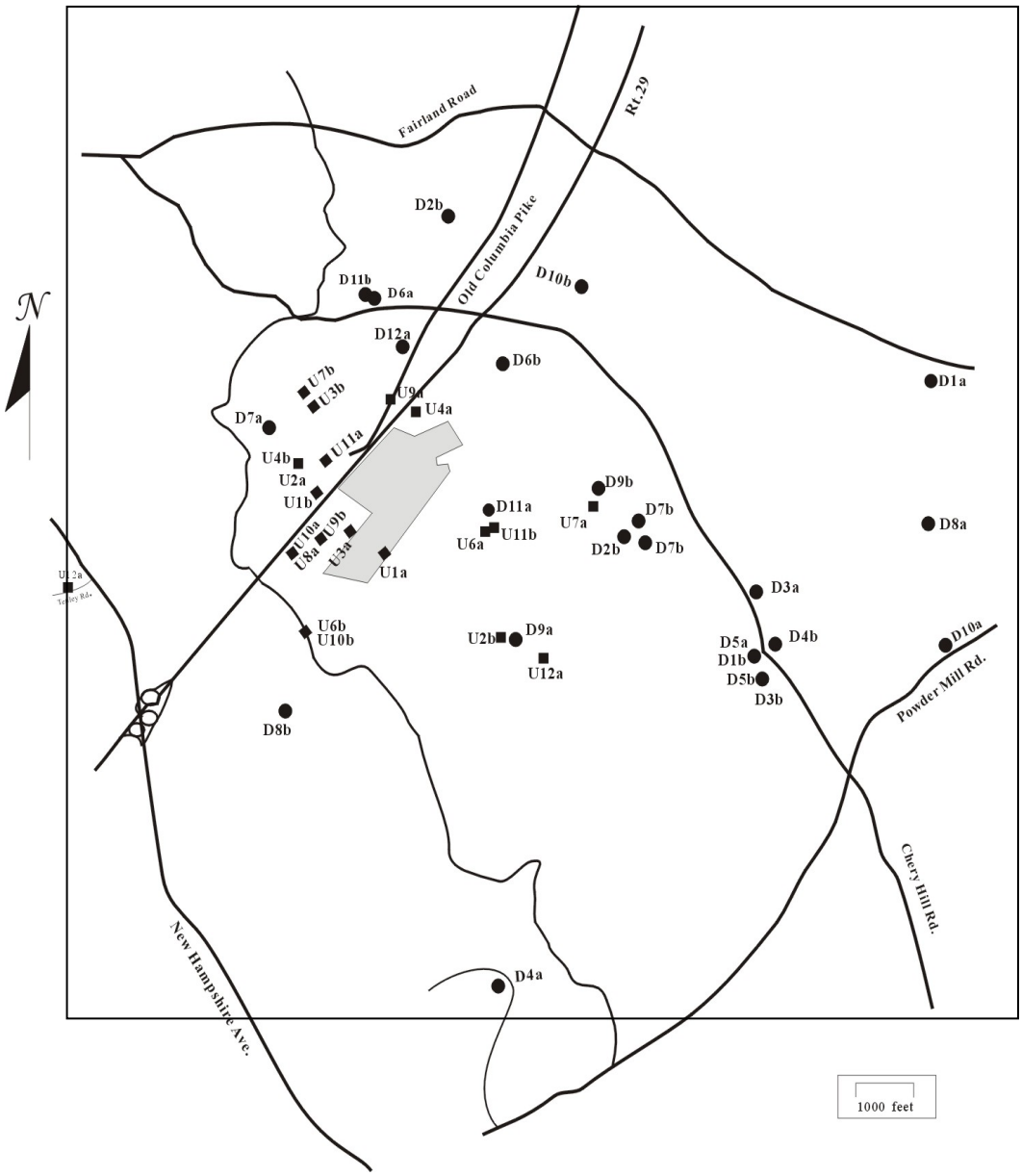

Figure 1. The sampling site of this study

2.2. The sampling procedure

In order to evaluate the contribution of bioaerosols from the composting facility, it was decided to sample the maximum concentrations. The downwind locations for maximum concentrations were predicted with an air dispersion model (ISCST). The model was calibrated for dispersion coefficients using meteorological data (wind speed, cloud cover and incoming solar radiation) collected at the weather station in the composting site. The times required for wind to travel from the upwind station to onsite and then to the downwind station were estimated with the meteorological data

at the time of sampling events.

Field sampling was performed twice a month at upwind, onsite and the predicted downwind locations. A total of 24 sets of sampling data were collected. The actual sites for sampling were determined, if accessible, from a site map of the area. Walkie -talkies were used during the entire sampling event for proper coordination. Proper travel times from the start of upwind sampling were allowed to elapse before the commencement of onsite and downwind samplings.It is believed that this sequential sampling characterizes the system better, as compared with the random sampling used by the previous study (Jones and Cookson, 1983).

Each sample was collected for 1 hour in duration, unless other specified.The selections for upwind and downwind locations were carefully examined on map before complete analysis of the concentration data. Table 1 describes the 24 sets of sampling locations for predicted downwind, actual upwind, and actual downwind stations carried out in this study. To prevent the possible backward dispersion from the site, a minimum of 600 m from the composting facility was required for the upwind site.

2.3. The sampling equipment

Andersen two-stage air samplers (Model 10-850) were used in this study. The Andersen samplers are aerodynamically engineered to collect viable airborne organic particles on a culture media.

The samplers were operated to suck air through them using a suction pump at a controlled pressure (14-16 psig Hg) to maintain a constant flowrate (1.0 m^3/min) for a specific time period.

The two-stage Andersen air samplers segregate particles into two components with a cutoff size of 8 μm. The collected samples were incubated in the laboratory. Culturing media with different nutrient formulations were used for the selection of different microorganisms.

2.4. The identification and quantification of the microorganisms

The bioassay procedure of this study follows the one developed by the previous study for investigation of this site (Jones and Cookson, 1983). Aerobic bacteria were determined on trypticase soy agar (TSA) plate incubated at 35 ^oC and scored at 24 hours and 48 hours after incubation. Cycloheximide was added to the TSA plates to inhibit fungal growth.

After 48 hour of incubation, aerobic bacteria were further analyzed for fecal coliform and fecal streptococcus. Each TSA plate was replicated onto MacConkey agar plates for coliform selection and KF Strep agar plates for streptococcus selection, by using disposable replica pads.Mesophilic fungi and thermophilic fungi were cultured on Oxygall (OX) agar plates.An antibiotic solution con taining penicillin G and chlorotetracyclin was added to the OX plates to inhibit bacterial growth. Mesophilic fungi were incubated at room temperature (20-25 ^oC) and thermophilic fungi at 45 ^oC. All of the OX plates were scored at the second and fourth days of incubation. *Aspergillus fumigatus* was identified morphologically on the thermophilic fungi plates. The *Aspergillus fumigatus* was characterized as growth with starburst-patterned green-gray fungal colonies that have off-white to cream-colored undersides.

The QA/QC program in this study was progressively developed to meet the needs, including laboratory control, trip control, field control, duplicate control, flowrate calibration and vacuum pressure check. A batch of media plates was prepared for each sampling event one week prior to the scheduled sampling date. If any of the laboratory control plates showed one or more colonies, the entire batch would be rejected.

Table 1. Predicted and actual sampling locations

Sample ID	Wind speed and direction (m/s)	Predicted downwind	Actual upwind	Actual downwind	QC check
1a(May)	(1.48, 250°)	(2438, 70°)	(457, 245°)	(2621, 70°)	Should use 2.68 m/s & 150°
1b	(5.72, 314°)	(305, 134°)	(914, 310°)	(1676, 125°)	O.K.
2a(June)	(4.65, 298°)	(305, 118°)	(792, 295°)	(914, 105°)	O.K
2b	(2.55, 182°)	(1524, 2°)	(579, 180°)	(1829, 0°)	O.K
3a(July)	(2.10, 262°)	(1524, 82°)	(610, 270°)	(1372, 110°)	O.K
3b	(2.24, 300°)	(1524, 120°)	(610, 310°)	(1676, 125°)	O.K
4a(Aug)	(2.19, 3°)	(1524, 183°)	(610, 355°)	(228, 185°)	O.K
4b	(2.41, 294°)	(1524, 114°)	(853, 295°)	(1676, 125°)	O.K
5a(Sep)	(3.93, 326°)	(610, 146°)	(762, 310°)	(1676, 125°)	O.K
5b	(2.32, 308°)	(1524, 128°)	(762, 310°)	(1676, 125°)	O.K
6a(Oct)	(2.46, 151°)	(1524, 331°)	(305, 150°)	(1585, 340°)	Upwind too short
6b	(2.77, 216°)	(914, 36°)	(914, 230°)	(884, 25°)	O.K
7a(Nov)	(2.06, 125°)	(1524, 305°)	(762, 105°)	(1158, 320°)	O.K
7b	(3.40, 303°)	(914, 123°)	(853, 310°)	(914, 100°)	O.K
8a(Dec)	(1.03, 271°)	(2438, 91°)	(610, 270°)	(2438, 90°)	O.K
8b	(2.68, 42°)	(914, 222°)	(610, 50°)	(1067, 220°)	O.K
9a(Jan)	(3.22, 335°)	(914, 155°)	(701, 345°)	(671, 170°)	O.K
9b	(3.08, 262°)	(914, 82°)	(610, 270°)	(762, 90°)	O.K
10a(Feb)	(1.43, 282°)	(2438, 102°)	(671, 260°)	(2362, 110°)	O.K
10b	(1.83, 225°)	(1524, 45°)	(884, 235°)	(1524, 35°)	O.K
11a(Mar)	(7.51, 317°)	(305, 137°)	(610, 310°)	(305, 130°)	O.K
11b	(1.97, 124°)	(1524, 304°)	(305, 125°)	(1585, 340°)	Upwind too short
12a(Apr)	(2.82, 171°)	(914, 351°)	(610, 170°)	(914, 355°)	O.K
12b	(1.65, 271°)	(2438, 91°)	(2438, 270°)	(762, 90°)	O.K

Note: The first number in parenthesis is distance in meters from the onsite and the secondnumber is the angle clockwise from true north

3. Results and discussion

3.1. The onsite levels of airborne microorganism

The sampling protocol required collection of onsite samples to estimate the stack discharge concentrations at the ventilation fan directly located on the roof of the active pile composting building. Since direct sampling on the roof was difficult, samples were taken underneath the fan at 1.5 m above the floor in the composting building. The floor air concentration (C_f) and the stack discharge concentration (C_0) under the steady state were considered to be equal. It was assumed

that the entire floor-level air subject to the onsite sampling was generated from the composting process inside the building, and all this air was ventilated through the roof fan.

The entire set of bioaerosol concentration measurements for each microbial group was reduced to the descriptive statistics given in Table 2.

Table 2. Aggregate bioaerosol concentrations and average emission rates at onsite of the composting plant

Microbial group	Concentrations (cfu/m^3)				Emission rate (cfu/hr)
	Range	Arithmetic mean	Geometric mean	95% Confidence interval	
Aerobic bacteria	4165-49914	16208	15415	11207-21203	5.2×10^7
Mesophilic fungi	176-9531	2469	2150	1256-3682	7.3×10^6
Thermophilic fungi	141-3620	1233	1181	879-1587	4.0×10^6
Aspergillus fumigatus	21-3611	574	448	215-933	1.5×10^6

The aggregate concentration ranges, arithmetic and geometric means, and appropriate 95% confidence intervals for the four microbial groups are included. The geometric mean concentrations of aerobic bacteria, mesophilic fungi, thermophilic fungi and *Aspergillus fumigatus* are 15415, 2150, 1181 and 448 cfu/m^3, respectively. Aerobic bacteria were emitted at concentrations approximately 6 times greater than the fungi. Mesophilic fungi were emitted at about twice the concentration as for thermophilic fungi.

Kothary et al. measured the levels of airborne *Aspergillus fumigatus* at various locations in a sewage sludge compost site. The levels between 2000 and 4000 cfu/m^3 were obtained 1 m downwind from the compost piles [2]. The levels of airborne *Aspergillus fumigatus* were measured for four compost plants in Sweden. At sites where material was processed, the number of airborne *Aspergillus fumigatus* exceeded 10^6 cfu/m^3 [1]. The level of airborne *Aspergillus fumigatus* obtained in this study is comparable to those found by Kothary et al., but much smaller than those found by Clark et al [1,2]. The difference may be related to the different wastes treated and the composting processes used.

The stack emission rate (J_s) from onsite can be calculated as $Q_0 \times C_f$, where Q_0 is the flowrate of the ventilation fan and C_f is the concentration measured at the floor beneath the fan. The emission rates of aerobic bacteria, mesophilic fungi, thermophilic fungi and were calculated to be 5.2×10^7, 7.3×10^6, 4.0×10^6 and 1.5×10^6 cfu/hr, respectively (Table 2). The ratios of the emission rate to amount of waste treated were also calculated as the emission factor. For aerobic bacteria, mesophilic fungi, thermophilic fungi and *Aspergillus fumigatus*, the emission factors were determined to be 3.1×10^6, 4.4×10^5, 2.4×10^5 and 9.0×10^4 cfu/wt or 1.6×10^7, 2.2×10^6, 1.2×10^6 and 4.5×10^5 cfu/dt, respectively. On average, the airborne *Aspergillus fumigatus* accounted for 38% of the thermophilic fungi at the onsite station, as compared to 59 - 98% found by Kothary et al [2].

3.2. Size distribution of airborne microorganisms

Table 3 gives the basic descriptive statistics derived from the aggregate particle size data, expressed as the percentage of particles

smaller than 8 μm. The aggregate range, arithmetic mean, geometric mean and 95% confidence interval of the fraction of particles smaller than 8 μm for each microbial group are given. Aerobic bacteria took up the least fine fraction ($d_p < 8$ μm) among the four microbial groups under study. The fractions of particles smaller than 8 μm for thermophilic fungi and *Aspergillus fumigatus* were similar (76.2% and 75.5%, respectively). Both these values were larger than that of mesophilic fungi (67.7%). This suggests that thermophilic microbes tend to exist in smaller sizes, as compared with the mesophilic ones.

Table 3. Statistics of the concentrations for four types of bioaerosols at the composting site

Microbial group	Fraction of particle < 8 μm (%)			
	Range	Arithmetic mean	Geometric mean	95% Confidence interval
Aerobic bacteria	31.8-52.8	41.3	41.2	39.4-44.4
Mesophilic fungi	18.2-97.4	70.3	67.7	54.5-73.4
Thermophilic fungi	50.0-97.1	76.2	76.2	70.1-81.1
Aspergillus fumigatus	37.2-100	76.0	75.5	67.7-83.0

3.3. Comparison of background concentrations

Ensuring that the wind directions were accurately determined and taken into account in sampling, the upwind concentration data would represent the background concentration. The data were analyzed for 95% confidence intervals using the student t-distribution. As shown in Table 4, the 95% confidence interval ranged from 75 to 173 cfu/m^3 for background total aerobic bacteria. The geometric mean was 114 cfu/m^3, which is higher than reported in the previous study (104 cfu/m^3) by Jones and Cookson [12]. The higher background concentrations were probably associated with lateral dispersion as a result of wind variations during sampling. The fine fraction accounted for 36% of the total aerobic bacteria, based on the geometric mean.

Table 4. Comparison of the background airborne microorganisms before and after operation of the composting facility

Microbial group	Before (Jones and Cookson, 1983) (cfu/m^3)	Operating (This study) (cfu/m^3)
Aerobic bacteria	50-121	75-173
Mesophilic fungi	212-337	262-706
Thermophilic fungi	2.1-3.2	5-14
Aspergillus fumigatus	0.9-1.8	2.3-12

Mesophilic fungi had been shown to be present at high concentrations (about 300 cfu/m^3) for typical suburban environments [12]. This implies that mesophilic fungi at the downwind station were more affected by background variation, and therefore, are not a good indicator, as compared to thermophilic fungi to evaluate the contribution from the composting operation. The upwind total mesophilic fungi concentrations were

higher than those of the previous study [12]. Naturally occurring airborne thermophilic fungi were not present at concentrations as high as aerobic bacteria and mesophilic fungi. The 95% confidence interval for the background concentration of thermophilic fungi was in the range of 5-14 cfu/m^3 and the concentration of *Aspergillus fumigatus* was found to be 2.3-12 cfu/m^3. Overall, the concentration levels of the background airborne microorganisms were noticeably higher after the plant operation.

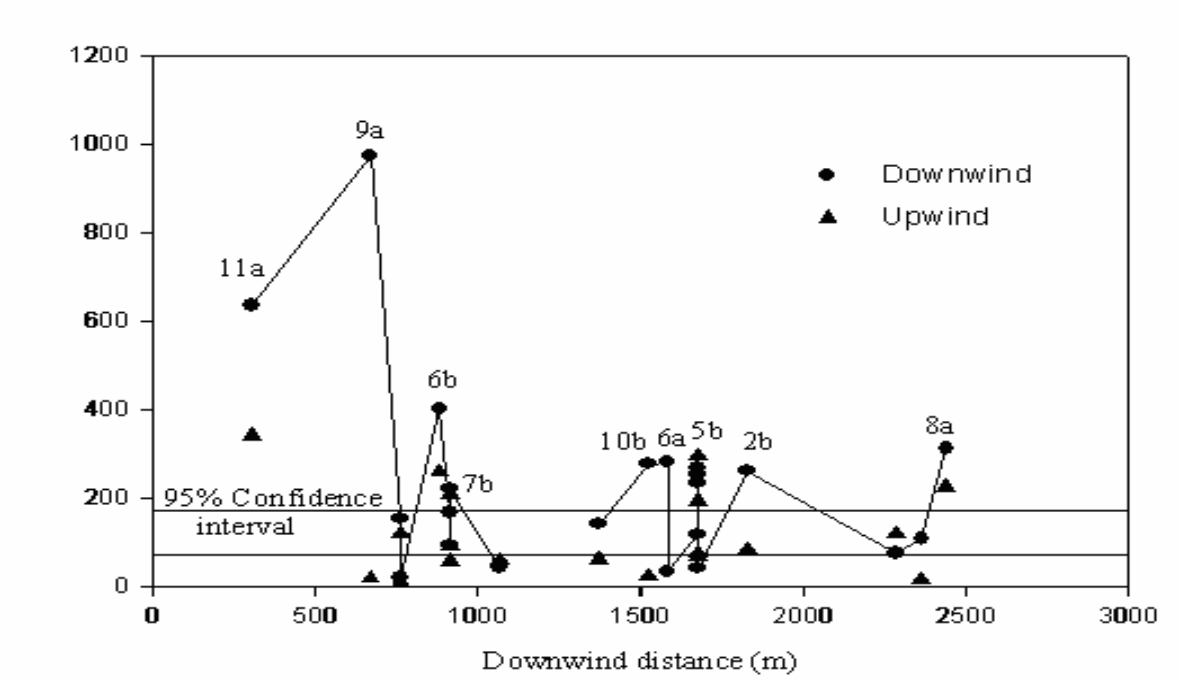

Figure 2. Comparison of the upwind and downwind concentrations of aerobatic bacteria vs. downwind distance, showing elevated downwind concentrations with a zone of in-fluence of 1500-2000 meter in radius

3.4. Upwind and downwind airborne microorganisms

Comparison between upwind and downwind concentrations provides information concerning the bioaerosol contributions by the compost facility. Concentrations of aerobic bacteria at upwind and downwind are plotted for comparison (Figure 2). The upwind concentration and its 95% confidence interval along with the downwind concentrations are plotted against downwind distance for comparison. The logic behind this plotting is that, based on air dispersion theory, the maximum downwind concentration decreases as the downwind distance increases.

Among the 19 usable data sets, 15 runs show downwind concentrations increased over the upwind concentrations and 4 runs show decreased at downwind stations. This is statistically significant at 5 % level with a given test. These plots clearly show that downwind aerobic bacteria concentrations increased from the 95% confidence interval of background concentrations for all the particles. The concentration was elevated to about 3 times at 300 m downwind and rapidly declined to the background level at a distance between 1200 to 1500 m (zone of influence). Small spikes at the greater distance appear to be systematic errors, when compared to the upwind points at the same distance.

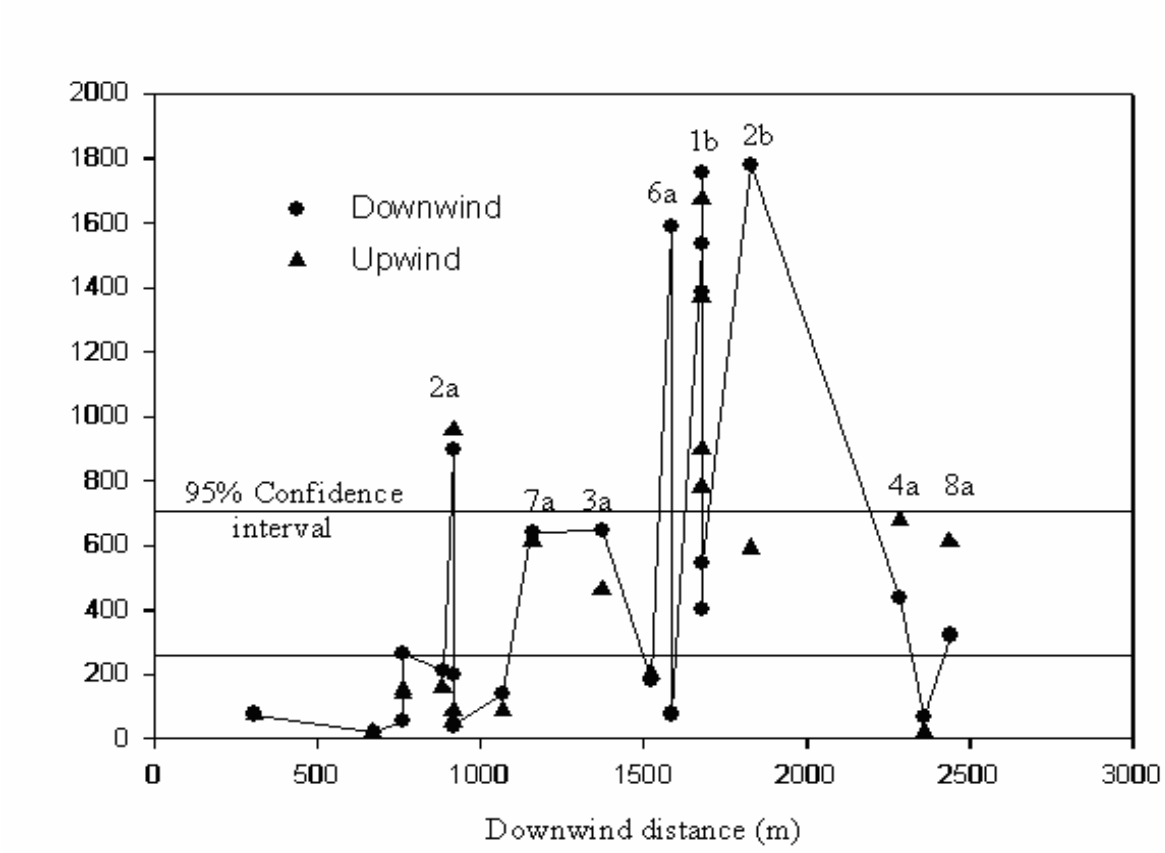

Figure 3. Comparison of the upwind and downwind concentrations of mesophilic fungi vs. downwind distance, showing no elevated downwind concentration

Figure 3 shows mesophilic fungi concentrations versus downwind distance plots for background 95% confidence interval and downwind concentrations. Discrete points for comparable upwind concentrations are also plotted. This plot demonstrates the concentrations of downwind mesophilic fungi, in general, fell within the background confidence intervals, except for a hump at the downwind distance between 1500 to 1800 m. This hump may be associated with systematic errors, since the background concentrations also increased to unusual levels outside the 95% confidence interval for these runs. The variation of downwind concentrations may be seasonal. The seasonal variation follows the same pattern for mesophilic fungi as previously reported by Jones and Cookson [12].

The thermophilic fungi concentration data are plotted for comparison between the upwind and downwind sites in Figure 4. Similarly the concentrations of *Aspergillus fumigatus* are shown in Figure 5. In general, these plots suggest that concentrations of viable thermophilic fungi increased by approximately 2 times from the 95% and upwind confidence intervals. The zone of influence was determined to be approximately 1500 m, similar to that for the aerobic bacteria. The increase of thermophilic fungi was, however, not likely associated with *Aspergillus fumigatus*. This suggests that the *Aspergillus fumigatus* died off during dispersion in the ambient air environment.

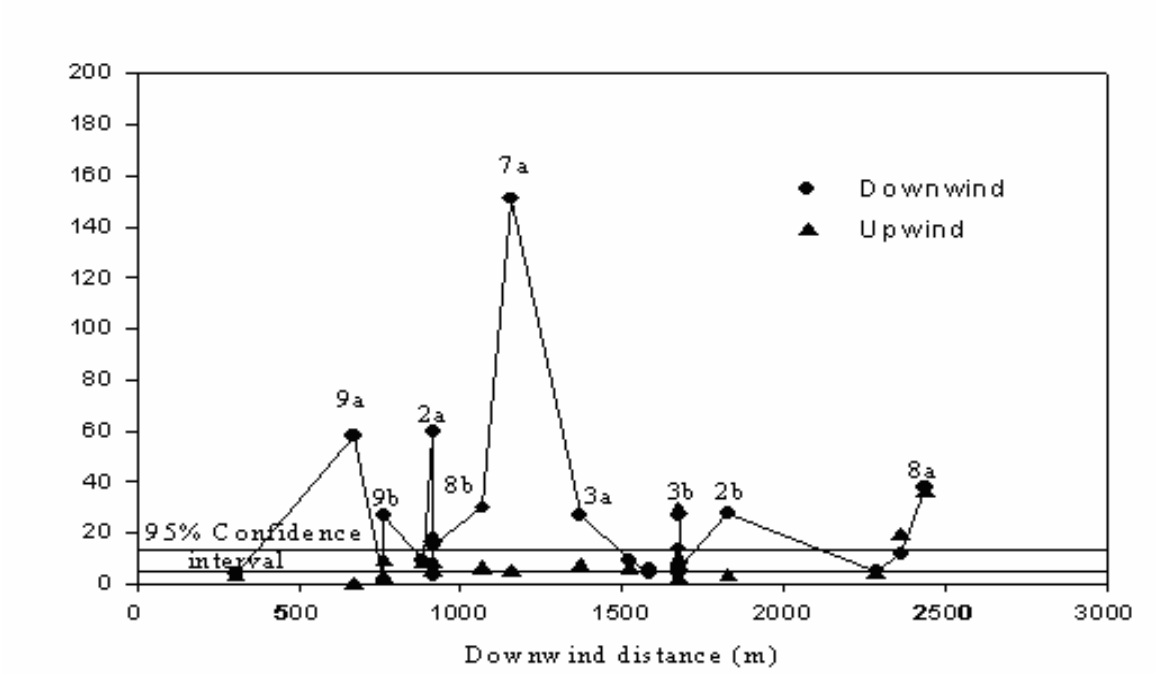

Figure 4. Comparison of the upwind and downwind concentrations of thermophilic fungi vs. downwind distance, showing elevated downwind concentrations with a zone of influence of 1500 meter in radius

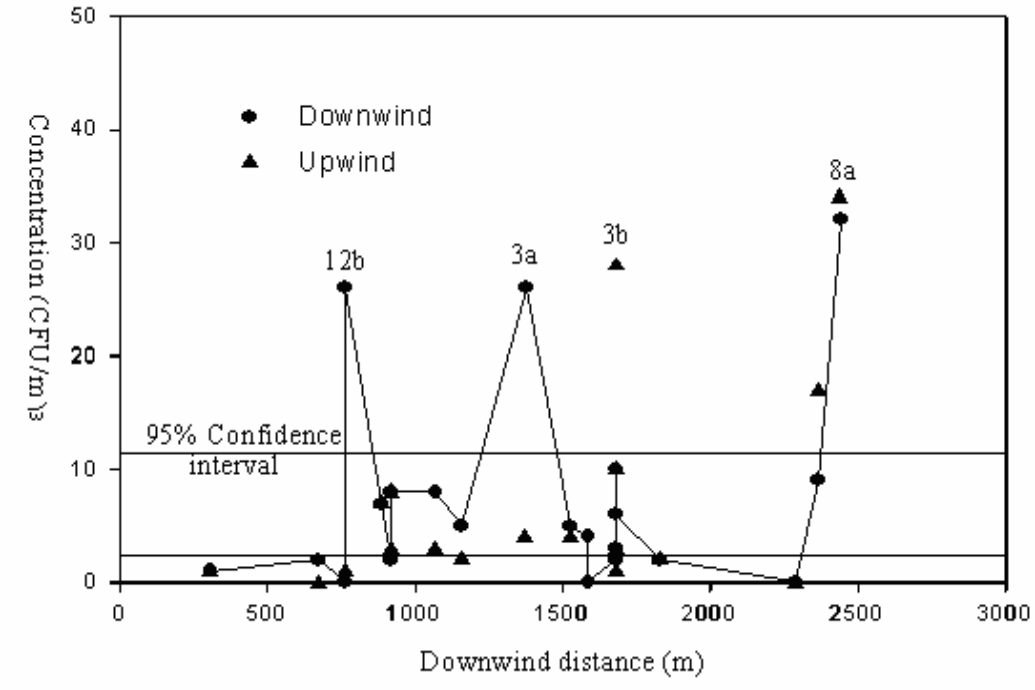

Figure 5. Comparison of the upwind and downwind concentrations of *Aspergillus fumigatus* vs. downwind distance, showing no elevated downwind concentration

4. Conclusions

Based on the results of this study, the following conclusions can be made relative to the bioaerosol emissions and ambient concentrations from the composting facility operation under study:

A sequential sampling scheme was proposed in this study. The upwind distance for sampling is suggested to increase from the current 600 to 1500 m from the facility to minimize the effect of lateral dispersion of bioaerosols, if the predicted wind direction deviates from the actual wind direction.

1. The average concentrations of aerobic bacteria, mesophilic fungi, thermophilic fungi, and *Aspergillus fumigatus* were determined to be 16208, 2469, 1233 and 574 cfu/m^3 at onsite with a variation coefficient of 140, 88, 151 and 69%.
2. Data collected at the onsite station suggest that the viable bioaerosols were emitted at a rate of 5.2×10^7 cfu/hr for aerobic bacteria, 7.3×10^6 cfu/hr for mesophilic fungi, 4.0×10^6 cfu/hr and 1.5×10^6 cfu/hr for *Aspergillus fumigatus*. And the emission factors were 3.1×10^6, 4.4×10^5, 2.4×10^5 and 9.0×10^4 cfu/wt or 1.6×10^7, 2.2×10^6, 1.2×10^6 and 4.5×10^5 cfu/dt for aerobic bacteria, mesophilic fungi, thermophilic fungi and *Aspergillus fumigatus*, respectively. Emissions of fine particles (< 8 μm) comprised approximately 40% for bacteria and 70-75% for fungi.
3. Comparison between downwind and upwind concentrations suggests that downwind levels were elevated for bacteria and thermophilic fungi. Elevated concentrations were not found for mesophilic fungi and *Aspergillus fumigatus*. Thermophilic fungi appear to be a better indicator organism, because their presence in the background environment is normally low.
4. The downwind bacterial concentrations decreased as the dispersion distance increased, and reached to the 95% confidence interval of the upwind concentration at a downwind distance of 1200 ~ 1500 m. A similar trend was not observed for thermophilic fungi.

Acknowledgements

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