Final Report **Project UKPIR 12**

Measurement and Modelling of Emissions from Three Composting Sites

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EXECUTIVE SUMMARY

UKPIR12: Bioaerosol and Odour Monitoring from Three Composting Sites (May, 2007)

Project funders/partners: SNIFFER, SEPA

Background to research

The focus of this project is on improving regulatory risk assessments. Ongoing research has improved the quality of source term data used in regulatory risk assessments and this study aimed to improve modelling of bioaerosols downwind of composting facilities, by examining the influences on variability of emissions.

Objectives of research

- Examine bioaerosol and odour emissions from in-vessel and open windrow composting facilities.
- Examine the seasonal differences in bioaerosol emissions
- Examine the bioaerosol emissions from different input materials
- Examine the downwind dispersal of bioaerosols and odour from composting
- Place the results of this study within the context of other published studies on bioaerosols and health impacts

In order to achieve these objectives, three different composting facilities were chosen as case studies, each representing different a composting system:

- Site A: Open windrow composting system (Green waste)
- Site B: Vertical, continuous flow silo cage composting system (Animal by-products waste)
- Site C: Thermally insulated in-vessel composting system (Municipal solid waste)

Bioaerosol samples were collected using a SKC personal air filter sampler. The bioaerosols examined were *Aspergillus fumigatus* and actinomycetes. The sampling locations at each facility were determined depending on facility layout and activities taking place during each site visit. Each site was visited on three different days during three different seasons to capture any seasonal variation, with a total of nine sampling days.

The odour sampling was carried out for all three composting sites during the summer, as it was estimated that odour concentrations would be highest during warmer conditions. A sampling hood was used for the windrow and silo cage composting systems to estimate the odour concentrations from static emissions, and 'stack' sampling was used for the municipal solid waste in-vessel composting system as these represent point source emissions only.

Key findings and recommendations

- The two in-vessel composting facilities had higher measured odour concentrations than the open windrow site. However, as they are both in-vessel, their impact on the surrounding communities might be minimised. The sampling at site C was carried out straight from the in-vessel units, before the biofilter that should control odour and bioaerosol emissions. Likewise planned installation of an exhaust management system at site B will help to control emissions at this site.

- The seasonal variation of *Aspergillus fumigatus* at all the three sites was up to 1-$\log_{10}$.
- For all sites, the concentrations of both *A. fumigatus* and actinomycetes in the autumn were higher than the concentrations detected in the summer and winter.
- For all sites and all seasons, the results indicated that background concentrations (such as upwind or downwind) of actinomycetes were lower than the concentrations from on-site activities and sources. For *A. fumigatus*, the results were less conclusive, with some of the on-site concentrations being lower than the background concentrations.
- Site C had the highest concentrations of actinomycetes during the summer and winter. Site A had the highest concentrations of actinomycetes during the autumn.
- The compost agar performed better as a growth media for actinomycetes compared to the half strength nutrient agar. The actinomycetes growth when using half strength nutrient agar was masked by other species of bacteria.
- In general, there was no link between the age of compost grab samples, their moisture content and the concentrations of micro-organisms detected in the compost grab sample.
- The concentration of micro-organisms in the compost grab samples was always higher than in the equivalent air sample.
- The results do not conclusively show which composting technology and which input material will consistently produce the highest bioaerosols emissions.
- Dispersion modelling of the static emissions shows that both dispersion models underestimate the downwind concentrations (in comparison to sampled concentrations) by 1- to 3-$\log_{10}$. For the agitation activities, the model predictions of downwind concentrations were within the same order of magnitude as the sampled concentrations, suggesting that the major contribution to downwind emissions was from agitation activities, as shown by other researchers.
- A comparison of the best and worst case emission scenarios revealed that sealing the leakage areas of the buildings at Site B may lower the downwind bioaerosol concentrations by up to 3-$\log_{10}$.
- The majority of the sampled concentrations reduce to below the suggested threshold limit value of Wheeler *et al*. (2001) of 1000 cfu/m^3 by 250 m downwind of the sites.
- The sampled concentrations are within the same range as previously reported at source measurements (e.g. Taha *et al*., 2006; 2007a)

Key words: bioaerosols, composting, risk assessment, dispersion modeling.

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1. INTRODUCTION

The steady growth in composting in the UK over the last ten years (Composting Association, 2006) is one response to the need to divert municipal solid waste (MSW) from landfill under the UK waste strategies, The European Waste Framework and the Landfill Directive. This growth requires local authorities and environmental regulators to permit the siting and operation of new compost facilities. Operating a compost facility should be a low hazard activity. However, composting does have the potential to cause pollution, harm to health and nuisance through odours, leachate, fires, dust, vermin and potentially harmful bioaerosols, if not operated properly (Pollard *et al*., 2004).

As a result of public health concerns and the need for operators to demonstrate the safe and responsible operation of their facilities, environmental regulators request regulatory risk assessments prior to licensing composting plants. Regulatory risk assessments allow operators to demonstrate they understand the hazards associated with their processes, and can design and implement technical and management procedures to minimise unacceptable risks. Regulators use risk assessments to inform environmental permitting and the drafting of conditions within the operator's licences or permits to operate.

Advising on a 'safe' distance between a composting facility and the neighbouring community is the responsibility of the planning authorities and the environmental regulator; yet what constitutes a safe distance is governed by the microbiological and aerodynamic properties of bioaerosols once released. The risk assessments undertaken to date have largely relied on single dispersion calculations to estimate concentrations of bioaerosols downwind from facilities and to allow comparisons with measured upwind or background data. In practice, the quality of risk assessments is highly dependant on the availability and quality of the bioaerosol source term data they employ. These data are frequently unavailable or limited, in part due to the practical difficulties of microbiological analyses and cost constraints.

The focus of this project is improving regulatory risk assessments. Ongoing research has improved the quality of source term data used in regulatory risk assessments (Taha et al., 2005; 2006; 2007a) and this study aimed to improve modelling of bioaerosols downwind of composting facilities, by examining the influences on variability of emissions. Regulators and environmental consultants, as end users of this research, will apply this understanding to improve the risk assessments required of the waste industry to support the permitting of compost plants.

1.1. Project Objectives

The general objectives of the project are:

- Examine bioaerosol and odour emissions from in-vessel and open windrow composting facilities.
- Examine the seasonal differences in bioaerosol emissions
- Examine the bioaerosol emissions from different input materials
- Examine the downwind dispersal of bioaerosols and odour from composting
- Place the results of this study within the context of other published studies on bioaerosols and health impacts

2. LITERATURE REVIEW

Composting facilities that are poorly operated have the potential to pose risks to sensitive receptors such as nearby residences and the environment (Pollard *et al*., 2004). In particular the risks are associated with bioaerosols, which are airborne micro-organisms and their constituents ranging from 10 nm to 100 µm in size (Aritya and Amyot, 2004). Environmental regulators require risk assessments from the operators of composting facilities in support of planning consent and environmental permits, in particular, where these facilities are within 250m of sensitive receptors (Environment Agency, 2001). These risk assessments should show that the operators are aware of potential risks and that they can take appropriate action to mitigate them.

However, gaps in our understanding of bioaerosol properties, particularly following their release from composting facilities, may result in under or over-estimating the levels of bioaerosols in and around composting facilities. This is due to the lack of sufficient information regarding their viability, inactivation, aggregation and dose-response relationships. The physical and microbiological characteristics of bioaerosols determine their behaviour, dispersal and potential adverse health effects in indoor and outdoor environments. In addition, it is currently not possible to compare the results of different studies because of the limited guidance regarding best practice in sampling and analysis methods. Hence different methods are used within various studies yielding inconsistent results. A detailed review of these issues can be found in Tamer Vestlund *et al*. (2007).

Furthermore, research has shown that bioaerosol emissions from composting facilities are episodic (Taha *et al*., 2006). The greatest emissions have been shown to be related to compost agitation activities, such as turning and shredding (Taha *et al*., 2006; 2007). However, the focus of most studies is on open windrow facilities, which fail to take into account the differences other technologies and input material may have on emissions. These are examined further in this study, along with the differences in emissions during different seasons. Finally, this study examines the emissions of odour from the three case study sites and predicts downwind dispersal of odour.

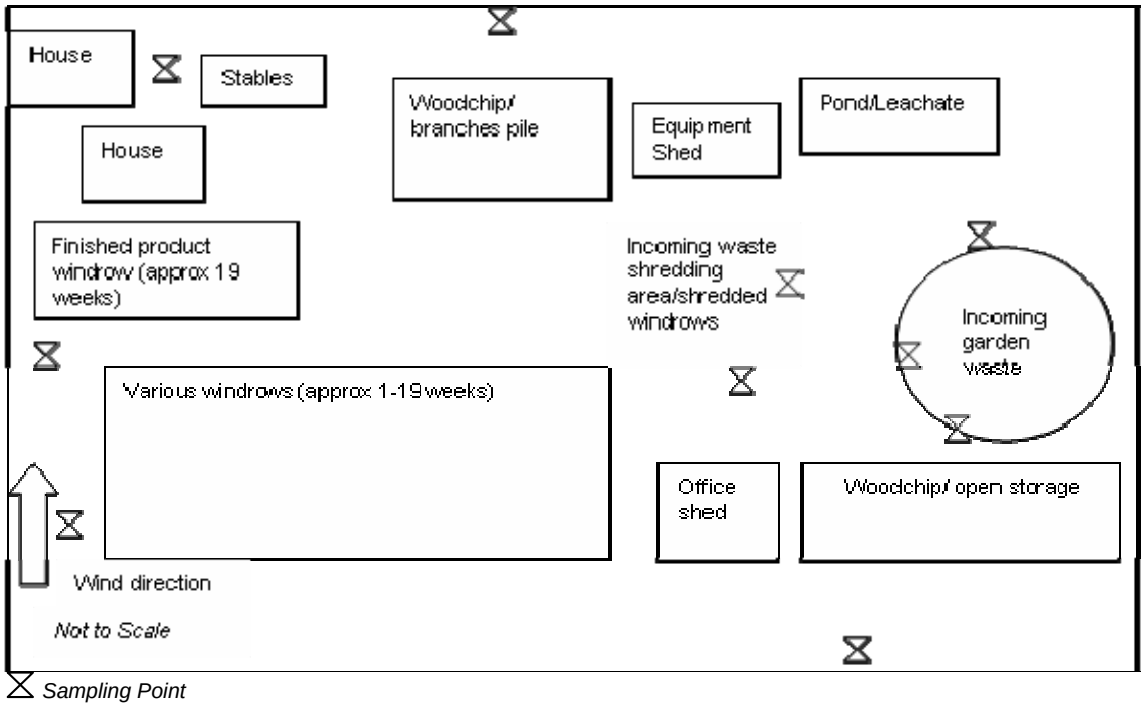
3. SITE DESCRIPTIONS

This study examines emissions from three different composting facilities, each using a different technology and processing different materials. The details of each site are described below.

3.1. Site A

Site A is a family operated open windrow composting facility in Aberdeenshire, Scotland. The site currently receives waste material from local councils in the form of green waste from kerbside collections and from local authority civic amenity centres. The estimated mass of processed waste is approximately 19 000 tonnes per annum, with approximately 5 000 tonnes of compost maturing on the site at the busiest time of the year. The maximum age of the compost on site is 19 weeks. There are currently plans to extend the process to include an in-vessel system and buildings to house processes such as screening and shredding. The site currently has an office, weighbridge and storage buildings. The owner and his family live in houses located adjacent to the composting facility. A small stable is also located next to the houses for the horse and pony owned by the family. The site is surrounded by agricultural land and the nearest receptor is a farm located approximately 500 m from the site boundaries. There is also livestock in the fields outside the site boundaries, the nearest of which is at a distance of about 200 m. The schematic diagram of this site is shown in Figure 1.

Figure 1 - Site layout and sampling locations for Site A



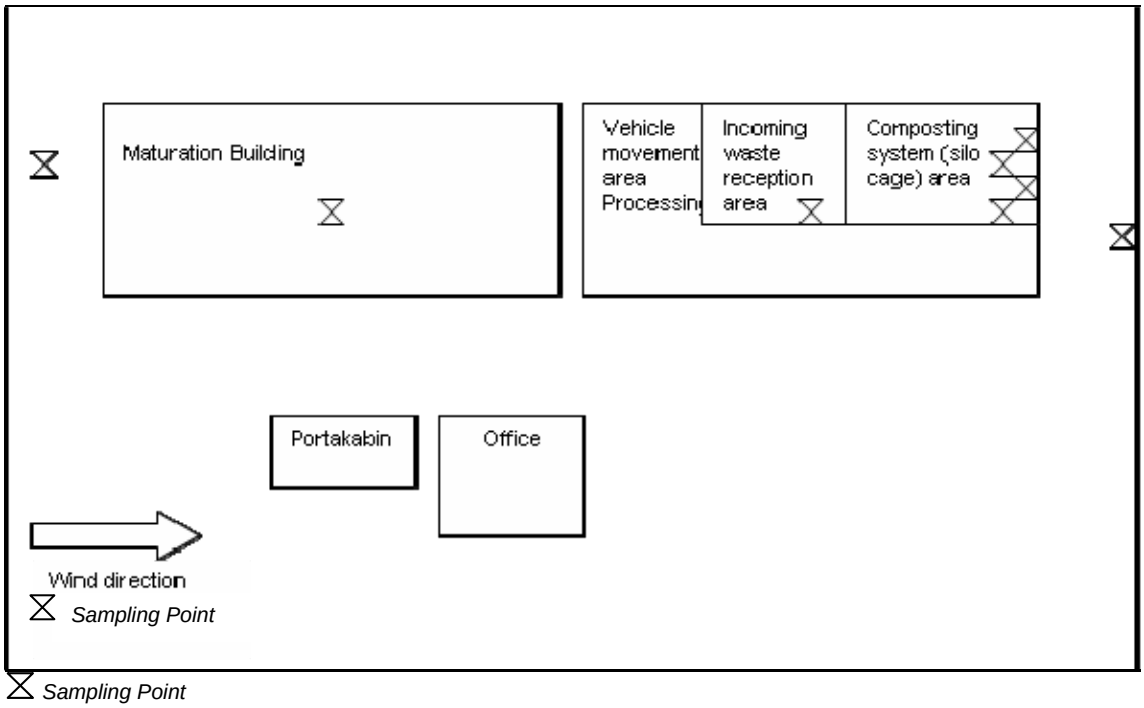
3.2. Site B

Site B is an in-vessel composting facility in Perthshire, Scotland. It is a vertical, continuous flow silo cage composting system, which does not employ forced aeration or mechanical agitation of the composting material. The residence time of the composting material is between 12 and 21

days. Pathogen control is by high temperature inactivation with temperatures of 70 - 80°C being maintained for typically 3 consecutive days. This site handles animal by-products (ABP), consisting mainly of chicken feathers with some hatchery and seafood waste. The ABP waste is mixed with chopped green waste, woodchip and sawdust in a pre-determined mass ratio. Chopped green waste collected from parks and gardens is used as the principal amendment material. On occasions, chicken litter is added to the waste mix. The layer of compost at the bottom of the silo cage is unloaded onto side conveyors by a trencher-type unloader, which runs beneath the silo cage and extracts the material. The compost is carried to an end cross conveyor and is collected at a discharge point in covered trailers, which take the material to the maturation shed. Once the bottom layer of compost is removed, the column of composting material in the silo drops under its own weight, leaving space at the top for fresh input material.

The composting system at this site is based inside the processing building and consists of 2 lines of 32 silos (6m length x 1.4m width x 4m height). The compost is then matured for about one month in the maturation building. In addition, a reception building is used to receive the ABP waste and amendment materials, as well as housing a wash down and vehicle movement area. A small office and portakabin are located near the entrance car park. The nearest sensitive receptor is a farm located approximately 300 m southwest of the facility. There is a landfill site approximately 300 m northeast and a green waste shredding facility, which belongs to the farm, approximately 200 m south of the facility. There is also livestock in the fields outside the site boundaries, the nearest of which is about 200 m south of the facility. The schematic diagram of this site is shown in Figure 2.

Figure 2 - Site layout and sampling locations for Site B



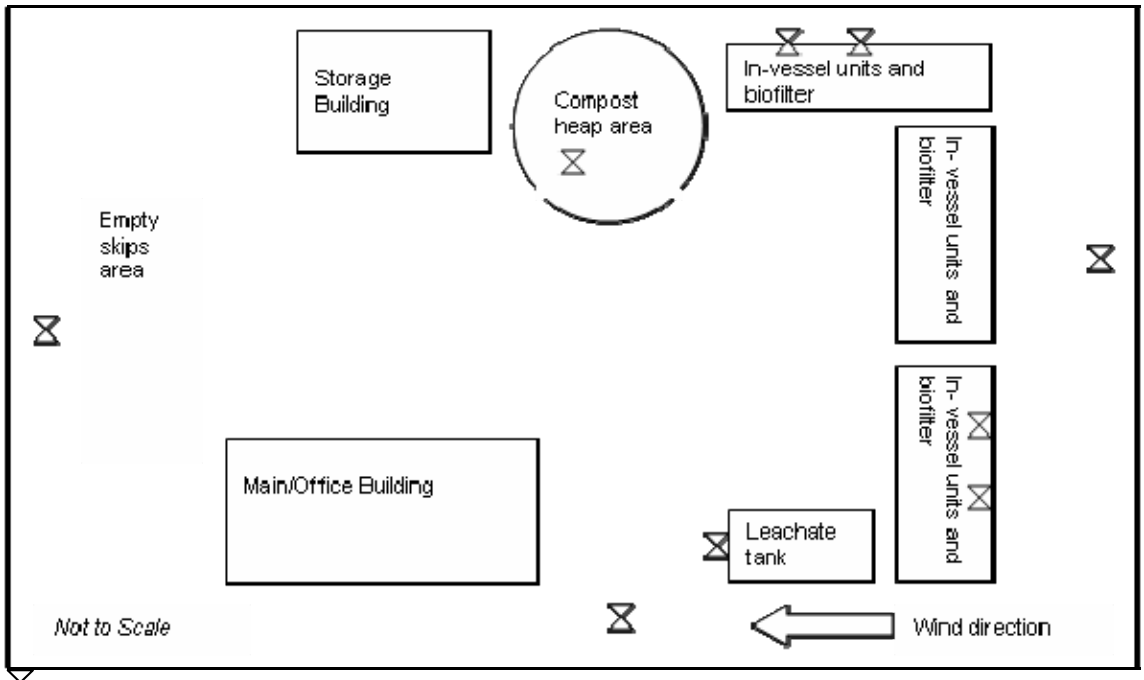
3.3. Site C

Site C is the second stage of a two-stage in-vessel composting process, used to comply with Animal By-Products Regulations, located in Aberdeenshire, Scotland. The first stage occurs at a

separate treatment plant, where municipal solid waste (MSW) is mechanically sorted to remove non-compostable elements. The biodegradable material then enters a Wright's in-vessel composting tunnel for approximately 7-14 days. After this period, the part degraded material is transferred to thermally insulated Alpheco in-vessel units at Site C for stage two of the composting process, where the material remains for 7-10 days. The material is then screened to remove any remaining non-compostable elements, before being sent off-site. The intake material to be treated is delivered directly to the treatment plants from the refuse collection vehicles. Some green waste may be added on a seasonal basis.

The site is un-manned and there are two buildings, a storage building and the workshop building, which also includes an office and rest facilities. A leachate tank is also present at this site. The site is surrounded by trees on all sides, lies adjacent to a busy road and is situated within agricultural land. The nearest receptor is a farm located 300 m from the site boundaries. The schematic diagram of this site is shown in Figure 3.

Figure 3 - Site layout and sampling locations for Site C



4. MATERIALS AND METHODS

4.1. Odour Sampling

The odour sampling at Site A took place on 5th July 2006. The odour samples were collected using a sampling hood (approximately 1.11 m x 0.17 m x 0.91 m), sampling drum and a portable pump as shown in Figure 4.

Figure 4 - Sampling hood, sampling drum and portable pump

The sampling hood was placed on the side of an incoming garden waste windrow (approximately 2 week old waste) and air was blown through the sampling hood. The portable pump was used to create a vacuum in the sampling drum, which then allowed the sample bag (Nalophan) to fill using the lung principle. The approximate size of the windrow was 22m x 10m x 4m (length, width, height). One odour sample was taken from the inlet of the sampling hood and three odour samples were taken from the outlet of the sampling hood. The sample bags took approximately five minutes to fill. The meteorological conditions, such as ambient temperature, relative humidity and wind speed, were recorded manually.

The odour sampling at Site B took place on 26th July 2006. The odour samples were collected using the same equipment and principles used at site A. The sampling hood was placed on top of a silo cage where the top layer of waste was 1 day old. The total height of the compost material sampled was approximately 4m high. The silo-cage is located indoors within the processing buildings. The ambient temperature, relative humidity and wind speed within the building were recorded manually.

The odour sampling at Site C was carried out on 9th August 2006. Due to a problem with the courier, these samples could not be validated as they were delivered to the laboratory 6 days after the samples were collected. Therefore another set of odour samples were taken on 20th September 2006. On both dates, the odour samples were collected using the sampling drum and portable pump only. Four samples were taken from the headspace inside the Alpheco in-vessel unit air extraction outlet. The samples were taken approximately 4m above ground. The in-vessel unit from which the odour samples were taken consisted of material that had just arrived at Site C, which meant that the compost was two weeks old.

4.2. Odour Analysis

The samples were couriered back to a UKAS accredited odour laboratory in Bedfordshire to be analysed using dynamic olfactometry. Olfactometry uses a panel of trained sniffers, who have been tested for their sensitivity against a reference gas (n-butanol). The samples were analysed by the odour panel within 24 hours of collection. The panel are presented with two ports, one with the odour sample and the other with odourless gas. The odour panel are forced to decide which port contains the odorous gas (forced choice method) at various dilutions of the odour sample. The concentration at which half the panel can no longer detect the odour is known as the detection threshold and is equivalent to $1ou_E$ (odour unit). The laboratory follows the BSEN13725 standard, "Air quality – Determination of odour concentration measurement by dynamic olfactometry".

4.3. Bioaerosol Sampling

For all three sites, the sampling points were located depending on the specific site details and the activities occurring during the site visit. The sampling points covered activities such as shredding, turning, and screening, as well as static emissions such as the windrow or in-vessel units, where the sampling hood was used. Sampling equipment was located at 1.8 m above ground for background samples, to represent the average height of a sensitive receptor.

Bioaerosol sampling was carried out using a personal air filter sampler (SKC; Figure 5), which draws a known volume of air through a filter medium where bioaerosols are captured. The IOM sampler head (as shown in Figure 5) was connected to the pump by a tygon tube (10mm diameter). The sampling cassette and filter (0.8 µm polycarbonate from SKC) were placed inside the IOM sampler head. The pump flow rate used for sampling was 2 ± 0.2 l/min as suggested by the equipment manual. The sampling time was 30 minutes if the bioaerosol concentrations were expected to be high, and 45 minutes for lower measurements, such as background concentrations (downwind and upwind).

Two pumps were used to take two simultaneous samples from each sampling point, with a third pump kept as standby and for blank measurements used to monitor background contamination during sampling and analysis. When analysing and reporting results, the average result from the two samples taken at each sampling point was used. All equipment, including the filter cassettes, filter heads and IOM sampler heads, was sterilised using an autoclave before being taken onto site. All pumps were calibrated before the start of sampling using a rotameter (variable area flowmeter) (SKC). During the summer site visits, bioaerosol and odour samples were taken simultaneously using the sampling hood. Two IOM sampling heads were placed in the top and bottom of the outlet chamber of the wind tunnel to capture the bioaerosol emissions.

Two compost grab samples of ca. 50 g were also taken from two different locations at each site on every visit to determine compost moisture content and micro-organism count.

A Kestrel 3000 pocket size anemometer (Meterologica Ltd., Lancashire) was used to determine wind direction, temperature, relative humidity and wind speed. General weather conditions, such as rain or strong winds, were recorded manually.

Figure 5 - Personal air sampler pump and 25 mm IOM sampling head (SKC Ltd.)

4.3.1. Pre-Sampling Laboratory Procedures

The micro-organisms measured in this study were *Aspergillus fumigatus* and actinomycetes. These micro-organisms were chosen as they are known to occur in large amounts during the composting process, pose possible health effects to sensitive receptors and have been widely studied in other research, making it possible to compare the results from this study with other published studies. Due to the nature of the sampling methods, only viable micro-organisms were sampled to estimate the concentration of bioaerosols.

Actinomycetes and *A. fumigatus* colonies were identified by visual inspection. Media preparation, inoculation, dilution and sterilization of all equipment used on site and in the laboratory were conducted in accordance with British Standard 5763 Part 0: General laboratory practices.

The actinomycetes were grown on two different agars, namely half strength nutrient agar (Oxoid) and a compost agar, developed by Taha *et al*. (2007b). The compost agar is agar-agar mixed with a supernatant of 10% w/w loam-based compost (John Innes No. 1). After preparation, the media were sterilised in an autoclave for 15 minutes at 115ºC and then allowed to cool to a temperature of 47ºC. Following this, the media were supplemented with 1% w/w cycloheximide in ethanol, to prevent the growth of fungi.

A. fumigatus was inoculated onto Petri dishes containing Malt Extract Agar (Oxoid). The media was treated with 0.01% w/w antibacterial chloramphenicol (Sigma) before sterilisation, as chloramphenicol is temperature resistant. The equipment was sterilised at the same temperature and for the same length of time as described for actinomycetes. The dissolved, sterilised and treated media was poured into Petri dishes at around 2 mm thickness and left to solidify in a laminar-flow safety cabinet for 30 minutes with half open lids.

4.3.2. Post-Sampling Laboratory Procedures

Immediately after sample collection, the sampling cassettes containing the filter were placed in a 30 ml vial (Nalgene) that contained a 10 ml solution of 0.05% w/w Tween-80, 0.1% w/w NaCl

and de-ionised water. This solution is used to prevent cell osmosis of the collected air sample during transport to the laboratory. The samples were placed in an ice-box maintained at < 4ºC. On return to the laboratory, the filter was separated from the filter cassette and then shaken in the vial for 1 minute using a rotamixer (Hook & Tucker Instruments). The solution was then diluted to a common logarithmic order and used to inoculate the Petri dishes. This occurred within 48 hours of sample collection, due to the distance between the laboratory and the sites.

The Petri dishes were incubated for 7 days at 44ºC for actinomycetes and for between 3-5 days at 37ºC for *Aspergillus fumigatus*, prior to counting by visual inspection. The actinomycetes were identified by their white powdery appearance, as well as their characteristic "spider web-like" filamentous structure, depending on the stage of growth. *A. fumigatus* was identified by its characteristic powdery blue-green appearance in the front and brown appearance at the back of the Petri dish.

On return to the laboratory, one gram of the compost from the wet compost sample was placed in a 30 ml vial (Nalgene), which contained 10 ml of a solution of 0.05% w/w Tween-80, 0.1% w/w NaCl and de-ionised water. The solution and the wet compost sample were shaken in the vial for 1 minute using a rotamixer (Hook & Tucker Instruments). Dilutions of this sample were prepared, inoculated and incubated for *A. fumigatus* and actinomycetes growth, using the same methods discussed above.

To determine the moisture content of the compost samples taken on site, the compost was weighed to determine its initial weight. The compost was then placed in an oven at a temperature of 100ºC until a consistent dry weight was achieved. The moisture content was calculated using the following equation:

$$MC = \frac{(Ww - Wd)}{Ww} x100$$

Equation 1

Where:

MC is the moisture content of compost;
Ww is the wet weight of compost; and
Wd is the dry weight of compost.

4.3.3. Expression of Results

Following incubation and enumeration, the results were expressed using the equations from with British Standard 5763 Part 0: General laboratory practices. If any of the inoculated plates had between 15 and 300 colonies, the concentration of bioaerosols in the sampling solution (N) was calculated using the following equation as a weighted mean from two successive dilutions:

$$N = \frac{\sum C}{V \times [n_1 + (0.1 \times n_2)] \times d}$$

Equation 2

Where:

$\sum C$ is the sum of the colonies counted on all the dishes retained from two successive dilutions, and where at least one contains a minimum of 15 colonies;
V is the volume of inoculums applied to each dish, in millilitres;
n_1 the number of dishes retained at the first dilution;
n_2 is the number of dishes retained at the second dilution; and

d is the dilution factor corresponding to the first dilution retained [d = 1 when the undiluted liquid product (test sample) is used].

If no plates contained more than 15 colonies, the estimated value of bioaerosols in solution (N) was calculated using equation 3:

$$N = \frac{\sum C}{V \times n \times d}$$ Equation 3

Where:

$\sum C$ is the sum of colonies counted on the two dishes;
V is the volume of the inoculums applied to each dish, in millilitres;
n is the number of dishes retained (in this case, n = 2); and
d is the dilution factor corresponding to the dilution retained.

The calculated concentration of the solution (10 ml liquid in 30 ml vial) was used to determine the concentration of bioaerosols in the sampled air in cfu/m^3 using equation 4:

$$B_{con} = \frac{N}{F_s \times t}$$ Equation 4

Where:

B_{con} is the sampled air bioaerosols concentration in cfu/m^3;
N is total number of bioaerosols in solution;
F_s is the air pumping or sampling flow rate; and
t is the sampling period.

All results were rounded to two significant figures.

4.4. Dispersion Modelling

The sampled bioaerosol concentrations were used in the SCREEN3 and ADMS 3.3 air dispersion models to estimate bioaerosol dispersal downwind of the activities and sources sampled. The properties of each source determined how it was modelled, either as a point, area or volume source. Each of these are described below.

4.4.1. Point sources

Point sources are described as controlled sources where emissions would be released into the atmosphere through a stack (e.g. a chimney). The average flow rate is measured using an anemometer across the area of the stack, with the flow rate being the product of the velocity and the cross-sectional area of the source.

The site C in-vessel Alpheco composting units were modelled as point sources. These vessels are thermally insulated with no means for bioaerosol or odour escape, apart from when the vessels are being emptied or loaded, which usually occurs off-site. The bioaerosol and odour samples were taken from the air outlet located at the top of the vessel, which is usually connected to a biofilter by a hose. Therefore, modelling these vessels as point sources is based

on the circumstances where the hose is disconnected from the air outlet, thereby providing an outlet for bioaerosol and odour emissions. The effects of building downwash and terrain have not been taken into account. Stability class D (neutral conditions) (Pasquill, 1961) was used for all modelling exercises, as this represents the most frequently occurring atmospheric state in the UK.

The following equation is adapted from odour measurement calculations (Jiang and Kaye, 2001) to calculate the bioaerosol emission rate for point sources. The same equation is also used to calculate the odour emission rate for point sources, however $B_{con}ER$ is expressed as *OER* (odour emission rate in ou_E/s) and *Bcon* is expressed as *OC* (odour concentration in ou_E/m^3).

$$B_{con}ER = QxB_{con} \qquad \text{Equation 6}$$

Where:

B_{con}	is the sampled air bioaerosols concentration in cfu/m^3;
Q	is the gas flow rate from stack (m^3/s); and
$B_{con}ER$	is bioaerosols emission rate (cfu/s).

The agitation activities of shredding and screening captured at site A were also modelled as point sources. It was not possible to directly measure the bioaerosol emissions rates at the point of release due to health and safety measures that must be taken to minimise risk of injury from agitation processes. Furthermore, as these are activities, and not static sources, it was not possible to use the wind tunnel to collect source term data. The bioaerosol emission rate was estimated by performing a back-extrapolation using SCREEN3, based on the known bioaerosol concentrations measured at 2 m and 10 m downwind of the agitation activity. Various emission rates were tested as inputs to SCREEN3, together with the measured mean temperature, wind speed and the height of sampling. The size of the dust cloud created by agitation was observed and the dimensions were estimated to be 3m x 3m x 3m.

4.4.2. Area sources

Sources such as the compost windrow (site A) and the compost silo cage (site B) were assumed to be area sources with outward flow and the wind tunnel method was employed to directly measure the emission rates. The basis of this method is to isolate a section of the emission surface and to force air to flow through this surface.

The bioaerosol samples were collected simultaneously with the odour samples using a sampling hood. The hood was placed on the side of a compost windrow at site A (approximately two week old waste). A second set of bioaerosol hood samples was taken from the right side of the same compost windrow, although only one set of odour samples was taken. On site B, the sampling hood was placed on top of the feedstock in the silo cage (waste approximately a few days old), located inside the processing building.

The net odour concentrations under the sampling hood were estimated by subtracting the inlet concentration from the average of the three outlet concentrations. The average of the two bioaerosol samples taken at the outlet was used for dispersion modelling.

The specific bioaerosol or odour emission rate (SBER or SOER) is the quantity of bioaerosols or odour emitted per unit time from a unit surface area. The equation used (equation 7) is adapted

from odour measurement calculations to calculate the bioaerosol emission rate for area sources (Jiang and Kaye, 2001).

$$SBER = \frac{Q \times BC}{A}$$ Equation 7

Where:

SBER is the specific bioaerosol/odour emission rate (cfu/m^2/s or ou_E/m^2/s);
Q is the flow rate through the sampling hood (m^3/s);
BC is the bioaerosol/odour concentration in air (cfu/m^3 or ou_E/m^3); and
A is the area covered by the wind tunnel (m^2)

All results were rounded to two significant figures.

4.4.3. Volume sources

The bioaerosol emissions ventilated from the processing, waste reception and maturation buildings at Site B were modelled as volume sources. The main problem when predicting the release of contaminants from buildings is the determination of the ventilation rate (Gostelow *et al*., 2003). Valentin and North's (1980) method of calculating the exhaust ventilation rate required to prevent the escape of air from buildings was adapted to calculate the flow rate used in the bioaerosol emission rate equations. The ventilation rate required to contain the airborne contaminants released within a building is dependent on the 'airtightness' of the building. Openings of the building, such as windows and doors, as well as structural imperfections, prevent buildings from being completely airtight. Movement of air through a building is the result of wind and temperature differences.

The design method of Valentin and North (1980) calculates an appropriate design wind speed and ventilation coefficient, based on the geographical area and building location, as well as the building height. In addition, infiltration areas are calculated for each building, which is defined as the sum of the areas of the gaps and openings (such as windows) in the least airtight external wall that directly faces the wind. The leakage areas of the two adjacent walls, (a) and (b), are calculated as:

$$A^1 = \frac{A_a + A_b}{AR}$$ Equation 8

Where:

A_a is the leakage areas of wall a (m^2);
A_b is the leakage areas of adjacent wall b (m^2);
AR is the aspect ration of the building (unitless); and
A^1 is the total leakage area of building (m^2).

If the leakage area of wall (a) or (b) is greater than A^1, then the leakage area from only that wall is used. If A^1 is greater than the leakage areas from either of the other walls, then A^1 is used to calculate the ventilation rate.

For buildings that have rooms along one or more sides, the infiltration area is determined using a different method. For areas of the waste reception building and waste processing building, which houses the silo cage composting system, the air has to pass through two walls in succession (because both of these buildings are rooms within the composting building). This

effectively decreases the infiltration area. In such cases, the infiltration area is calculated using equation 9:

$$\frac{1}{A_e^2} = \frac{1}{A_{ow}^2} + \frac{1}{A_{iw}^2}$$ Equation 9

Where:

A_e is the effective leakage area (m^2);
A_{ow} is the leakage area of outer walls of rooms (m^2); and
A_{iw} is the leakage area of inner walls of rooms (m^2).

From these inputs, the ventilation rate required is calculated as:

$$V = C \times A$$ Equation 10

Where:

V is the ventilation rate (m^3/s);
C is the ventilation coefficient calculated from tables (unitless); and
A is the infiltration area of building (m^2).

Finally, the following equation is adapted from odour measurement calculations to calculate the bioaerosol emission rate for release from buildings, as described in Equation 6 above (Section 4.3.1):

$$B_{con}ER = VxB_{con}$$ Equation 11

Where:

B_{con} is the sampled air bioaerosols concentration in cfu/m^3;
V is the ventilation rate (m^3/s); and
$B_{con}ER$ is bioaerosols emission rate (cfu/s).

The design wind speed from Valentin and North (1980) was 15m/s as the site is located in North Scotland. This is the maximum wind speed exceeded for 2% of the time. From Valentin and North (1980), the ventilation coefficient used for these buildings was 9.8 as this is an exposed site (the buildings are not completely sheltered by adjacent structures) and the height of all buildings is 6.5m.

The maturation building is a stand alone building that has no rooms inside. It has 4 walls, 3 of which have a metal shutter (7m x 3m) and a safety door (1m x 1.8m) and the final wall has a safety door (1m x 1.8m). There are no windows or other leakage areas and cladding effects were not taken into account. This building had an aspect ratio of around 3.6. The Valentin and North (1980) method is appropriate for buildings that are square or nearly square (up to an aspect ratio of 1.5). However in the absence of more appropriate methods, the Valentin and North (1980) method was used for this building and the aspect ratio was assumed to be 1.5. It was also assumed that the roof slope angle was less than 45° from horizontal and thus there was no need to account for leakage areas from the roof.

The processing and waste reception buildings are both housed inside the main composting building, however for modelling purposes they are modelled as stand alone buildings, keeping in mind that air has to flow through two successive walls in certain areas. The infiltration areas for these buildings were therefore determined using Equation 9, which was also used to

determine the infiltration area of the maturation building. The processing building has no rooms inside, has 4 walls, one of which has a metal shutter (7m x 3m) and a safety door (1m x 1.8m), the second wall has a safety door (1m x 1.8m) and the third wall has a safety door (1m x 1.8m) and a small outlet (1m x 1m) where composted material exits the building. The final wall has no leakage areas. There are no windows and for cladding effects, a leakage area of about 0.1 m^2 per metre of wall was assumed. This building had an aspect ratio of around 1.5. The waste reception building has no rooms inside, has 4 walls, one of which has a metal shutter (7m x 3m) and the second wall has a safety door (1m x 1.8m). The final two walls have no leakage areas. There are no windows and for cladding effects, a leakage area of about 0.1 m^2 per metre of wall was assumed. This building had an aspect ratio of around 1. For both buildings it was again assumed that the roof slope angle is less than 45º from horizontal, so leakage areas from the roofs were not taken into account.

Two different scenarios for modelling were considered for the buildings. The 'worst case scenario' assumed that the leakage areas (metal shutters, doors and other openings) of the two adjacent walls affected by the wind were open at all times. The 'best case scenario' assumed that these leakage areas were kept closed at all times. For the 'best case scenario', there will still be some leakage from the infiltration areas; therefore the following leakage is assumed based on Valentin and North (1980):

Windows	0.001 m^2 per metre of opening joint
Doors	0.002 m^2 per metre of opening joint

5. Results

5.1. Odour Sampling

The results from the odour sampling are presented in Table 1, showing that the highest odour emissions were from the animal by-products in-vessel compost facilty (site B). This is an expected result due to the nature of the feedstock. However, as this is an in-vessel facility where the silos are housed inside a building, the impact on local neighbours may be reduced by the planned installation of an exhaust management system and negative aeration within the processing building. The MSW in-vessel system at site C produced the second highest odour concentrations, but as these vessels are entirely sealed, the impact on neighbours might only be felt under exceptional circumstances, such as the failure of the biofilter unit. The green waste windrow site had the lowest measured odour concentrations.

Table 1 - Odour concentrations measured at the three sites

Site	Inlet odour concentration (ou_E/m^3)	Outlet odour concentration (ou_E/m^3)	Geometric mean of outlet odour concentration (ou_E/m^3)
A	1,611	2,144	
		2,260	
		454	1,301
B	19,060	38,393	
		26,121	
		19,426	26,908
C1*		3,765	
		3,990	
		5,370	
		6,047	4,700
C2		7,833	
		11,689	
		7,790	
		10,834	9,376

*Note: Due to a problem with the courier, these samples could not be validated as they were delivered to the laboratory 6 days after the samples were collected.

5.2. Bioaerosol Sampling

5.2.1. Summer Results

The results from the summer bioaerosol sampling at sites A, B and C are presented in Table 2, Table 3 and Table 4, respectively. The sampling was carried out at site A on 5th July 2006, at site B on 26th July 2006 and at site C on 9th August 2006. Generally the weather conditions were dry and sunny with a light breeze, apart from at site C, where brief spells of drizzle were noted. At sites A and B, there was heavy vehicle movement with vehicles bringing material onto site and taking end product away from site during the sampling. In addition, at site B, traffic to

and from the nearby landfill frequently passed the site. There was no traffic at site C as this is an unmanned site. Details of the sampling conditions for all sites are presented in Appendix I.

For all three sites, the concentrations of *Aspergillus fumigatus* were lower than the concentration of actinomycetes, especially for site C, where no *A. fumigatus* was detected at 4 out of the 5 locations sampled. The background and source emissions of *A. fumigatus* for the three sites did not show great variation and were within the range of 0.8 - 9.9 x 10^3 cfu/m^3. In contrast the concentrations of actinomycetes for the three sites varied between 2.0 - 79.0 x 10^3 cfu/m^3.

At site A, the sampling hood was used to sample two sides of the same compost windrow. The concentration of actinomycetes on the right side of the windrow (18.9 x 10^3 cfu/m^3) was 1-$\log_{10}$ higher than on the left side of the windrow (8.3 x 10^3 cfu/m^3), although the *A. fumigatus* concentrations on both sides were similar (left side 9.9 x 10^3 cfu/m^3; right side 8.7 x 10^3 cfu/m^3). All samples were taken from the same compost windrow on the same day. However, micro-organism concentrations throughout the windrow were not expected to be the same as variations can occur due to changes in temperature and composition of the heterogeneous material.

No *A. fumigatus* was detected upwind at sites B and C. For the downwind measurements, site B showed the highest concentration of *A. fumigatus* (5.3 x 10^3 cfu/m^3). The highest upwind concentrations of actinomycetes were detected at site C (4.5 x 10^3 cfu/m^3), but downwind actinomycetes counts were higher at sites A and B. However, site B is adjacent to a landfill site, a green waste shredding facility and a farm, and next to a busy road with traffic moving to and from the landfill site. Therefore, a high background concentration of bioaerosols is expected due to the interference from these other sources, especially from the green waste shredding facility and the farm. The interference from the landfill site is likely to be less significant as it is located downwind of the site, with the prevailing wind direction predominantly from the south and south west. The high concentrations could also be attributed to the feedstock material (animal by-products) that is being composted, in comparison to green waste and municipal solid waste being processed at the other two sites.

The actinomycetes emissions detected inside Vessel 77 on site C showed the highest concentration (79.4 x 10^3 cfu/m^3) out of all the summer results for all the sites. However, as these vessels are entirely sealed and the location is remote, the impact on local neighbours is likely to be minimal.

At site A, the concentrations of bioaerosols measured using the sampling hood on the static compost windrow were of the same order of magnitude as the background concentrations, including the concentrations detected near the houses located adjacent to the composting facility. The only exception to this was the right hand side sampling hood actinomycetes concentration, which was 1-$\log_{10}$ higher than the background emissions. However no shredding, turning or screening activities were observed that day, which could increase the emission of bioaerosols from this facility during other periods.

At site C, higher concentrations of actinomycetes were detected from Vessel 77 where the stored compost is around 5 weeks old, compared to the lower concentrations from Vessel 66 where the compost is approximately 3 weeks younger. The actinomycetes concentrations in Vessel 66 were similar to the concentrations of actinomycetes detected inside the site B processing building (1-21 day old compost) and the site A incoming waste compost (less than 5 days old).

Although both the half strength nutrient agar and the soil compost agar were used to inoculate actinomycetes, it was not possible to enumerate actinomycetes on the half strength nutrient

agar due to the over-growth of other bacteria on the Petri dishes. This was found at all sites during all seasons. The actinomycetes results presented are therefore those grown in the compost agar.

Table 2 - Site A summer bioaerosol sampling results

Sample Location	Actinomycetes in air sample (cfu/m^3) x 10^3	*A. fumigatus* in air sample (cfu/m^3) x 10^3
Upwind	No actinomycetes detected	1.3
Sampling hood right	18.9	8.7
Near houses	2.0	0.8
Sampling hood left	8.3	9.9
Downwind	7.1	1.4

Table 3 - Site B summer bioaerosol sampling results

Sample Location	Actinomycetes in air sample (cfu/m^3) x 10^3	*A. fumigatus* in air sample (cfu/m^3) x 10^3
Upwind	2.5	No *A.fumigatus* detected
Processing building-sampling hood (top of silo)	9.1	7.6
Processing building - bottom of compost silo	15.9	3.0
Processing building - next to conveyor belt	6.8	1.5
Downwind	7.3	5.3

Table 4 - Site C summer bioaerosol sampling results

Sample Location	Actinomycetes in air sample (cfu/m^3) x 10^3	*A. fumigatus* in air sample (cfu/m^3) x 10^3
Upwind	4.5	No *A.fumigatus* detected
Vessel 66	8.1	1.3
Leachate tank	4.0	No *A.fumigatus* detected
Vessel 77	79.4	No *A.fumigatus* detected
Downwind	3.0	No *A.fumigatus* detected

5.2.2. Autumn Results

The results from the autumn bioaerosol sampling at Sites A, B and C are presented in Table 5, Table 6 and Table 7, respectively. The autumn sampling was carried out at site A on 18th October 2006, at site B on 4th October 2006, and at site C on 20th September 2006. The sampling conditions were rainy and cloudy with a light breeze at site A, dry and clear with a light breeze at site B and cloudy with a light breeze at site C. Traffic movement were similar to those observed during the summer site visits, apart from activities such as screening, turning and shredding occurring at site A during sampling. Details of the sampling conditions for all sites are presented in Appendix II.

In line with the results of the summer results, the concentrations of *Aspergillus fumigatus* were lower than the concentrations of actinomycetes for all sites, especially for site C, where no *A. fumigatus* was detected at 3 out of the 5 locations sampled. The concentrations of *A. fumigatus* for the three sites again showed little variation, with the exception of the site B sample from the top of the line 1 silo cages, where a concentration of 400.0 x 10^3 cfu/m^3 was measured. In this sampling location, the concentrations of *A. fumigatus* detected were much higher than the actinomycetes concentrations. Apart from this one high value, the concentrations of *A. fumigatus* for the three sites were within the range of 0.7 – 85.6 x 10^3 cfu/m^3. In contrast, the concentrations of actinomycetes for the three sites varied between 6.8 – 2460.0 x 10^3 cfu/m^3. This maximum is higher than all the concentrations detected during the summer.

The highest upwind and downwind concentrations of actinomycetes were detected at site A (56.9 x 10^3 cfu/m^3). *A. fumigatus* was only detected upwind at site B, where the highest downwind concentrations were also measured. This could be attributed to the other facilities that surround site B as previously discussed.

At site A, the same locations sampled during the summer were sampled again. As the sampling hood was unavailable, the IOM sampling heads were placed as close to the compost as possible, which resulted in higher concentrations for both micro-organisms compared to the summer. It is possible that the different sampling methods influenced the results, increasing the difficulty in comparing these two data sets. The age of compost on this windrow was the same as during the summer site visit. However during the autumn site visit, some unloading activity occurred very near to the sampling point and this could also have contributed to the increase in detected concentrations. Possible contamination of the filter by compost particles due to the proximity of the sampler to the compost may also have influenced the results.

At site A, the background concentrations were generally higher than the summer results, but lower than any on-site measurements. The samples from the compost windrow had the highest concentrations of *A. fumigatus* at 45.8 x 10^3 cfu/m^3. However the highest concentrations of actinomycetes were recorded near the shredding/screening activity at 2460.0 x 10^3 cfu/m^3.

For site B, the concentrations of actinomycetes were highest in the maturation and reception buildings, despite the higher level of activity occurring in the processing building. The concentrations of both micro-organisms were higher compared to the summer results, however the feedstock contained some chicken litter in the autumn that might have contributed to this increase.

For site C, both micro-organisms had higher background concentrations compared to the summer results. In line with the summer results, the concentrations of actinomycetes were much higher from Vessel 77 where the stored compost was approximately 5 weeks old, compared to the concentrations detected in Vessel 78 where the stored compost was approximately 2 weeks old.

For all sites, the concentrations detected for both *A. fumigatus* and actinomycetes were higher than the concentrations detected in the summer.

Table 5 - Site A autumn bioaerosol sampling results

Sample Location	Actinomycetes in air sample (cfu/m^3) x 10^3	*A. fumigatus* in air sample (cfu/m^3) x 10^3
Upwind	56.9	No A.fumigatus detected
On incoming waste	766.2	45.8
Next to incoming waste	147.7	8.7
Near house	73.5	2.8
On screening machine	2460.0	6.4
Other side of activity	269.3	3.0
Downwind	76.4	1.5

Table 6 - Site B autumn bioaerosol sampling results

Sample Location	Actinomycetes in air sample (cfu/m^3) x 10^3	*A. fumigatus* in air sample (cfu/m^3) x 10^3
Upwind	13.6	19.7
Top of compost silo cage, line 2	45.7	2.3
Top of compost silo cage, line 1	19.3	400.0
Next to active conveyor belt	56.1	85.6
Next to passive conveyor belt	13.3	3.8
Inside waste reception building	497.2	1.5
Inside maturation building	481.8	20.4
Downwind	12.1	4.5

Table 7 - Site C autumn bioaerosol sampling results

Sample Location	Actinomycetes in air sample (cfu/m^3) x 10^3	*A. fumigatus* in air sample (cfu/m^3) x 10^3
Upwind	6.8	No *A.fumigatus* detected
Vessel 78	64.6	17.0
Leachate Tank	17.4	No *A.fumigatus* detected
Vessel 77	462.1	No *A.fumigatus* detected
Next to Windrow Compost Pile	11.6	No *A.fumigatus* detected
Downwind	26.1	0.7

5.2.3. Winter Results

The results from the winter bioaerosol sampling at sites A, B and C are presented in Table 8, Table 9 and Table 10, respectively. The winter sampling was carried out at site A on 15th November 2006, at site B on 29th November 2006, and at site C on 8th November 2006. The sampling conditions were clear with a light breeze, apart from at site C, where the conditions were cloudy and rainy. Traffic movements at all three sites were very similar to those observed

during the autumn site visits and details of the sampling conditions for all sites are presented in Appendix III.

In line with the summer and autumn results, the concentrations of *Aspergillus fumigatus* were generally lower than the concentrations of actinomycetes for all sites (apart from the two concentrations detected at site A adjacent to the compost windrow and on the mature compost windrow). At site C, no *A. fumigatus* were detected at 4 out of the 6 locations sampled. The concentrations of *A. fumigatus* for the three sites showed little variation and were within the range of 1.5 – 23.5 x 10^3 cfu/m^3. In contrast, the concentrations of actinomycetes for the three sites varied between 4.0 – 9.36 x 10^3 cfu/m^3.

The results show that the background concentrations at site C were the highest concentrations for both *A. fumigatus* and actinomycetes, in contrast to the summer and autumn results. There was very little vehicle activity at this site, compared to the other sites, and the heavy rain observed throughout most of the site visit were expected to reduce, and not increase, the concentrations of bioaerosols in the environment.

For site A, it was not possible to sample the compost windrow that was sampled in the summer and autumn due to heavy activity occurring at that location. However, the concentration from an ambient sample taken nearby was much lower in the winter sampling season (6.1 x 10^3 cfu/m^3 as opposed to 147.7 x 10^3 cfu/m^3). Some agitation activity was observed during sampling at this location during both visits. In addition, the background concentrations (upwind and downwind) were also much lower in the winter than in the autumn, but similar to the summer results. Therefore the effect of temperature is unlikely to have caused the lower concentrations. Interestingly, the concentrations of bioaerosol detected on the newly shredded compost windrow were higher than the concentrations detected near the shredding activity. This was also the location with the highest concentration of actinomycetes (93.6 x 10^3 cfu/m^3) detected at this site. However, the highest concentration of *A. fumigatus* was recorded at the mature compost windrow (23.5 x 10^3 cfu/m^3).

For site B, the concentrations of actinomycetes were similar in the processing, maturation and reception buildings, with the winter concentrations being the highest out of all the seasons. The summer and winter feedstock did not contain any chicken litter, unlike in the autumn. This suggests that adding chicken litter to the feedstock is unlikely to result in different emissions of bioaerosols. The concentrations of *A. fumigatus* were similar to the summer and autumn results.

For site C, the winter background concentrations for both micro-organisms were higher than in the summer and in the autumn. In contrast to the summer and autumn sampling results, the concentrations of actinomycetes were 1-$\log_{10}$ higher from the younger compost (Vessel 78 ca. 10 week old compost - 155.3 x 10^3 cfu/m^3), compared to the older compost (Vessel 77 ca. 12 week old compost – 63.7 x 10^3 cfu/m^3). The concentrations of *A. fumigatus* were low or undetected for this site, in line with the summer and autumn sampling results.

In general, for all sites, the concentrations of both *A. fumigatus* and actinomycetes were slightly higher than the concentrations detected in the summer and autumn.

Table 8 - Site A winter bioaerosol sampling results

Sample location	Actinomycetes in air sample (cfu/m^3) x 10^3	*A. fumigatus* in air sample (cfu/m^3) x 10^3
Upwind	6.8	No *A.fumigatus* detected
On shredded waste	93.6	4.5
Next to incoming waste	6.1	15.5
Near houses	4.0	No *A.fumigatus* detected
Shredding activity	40.9	7.6
Mature compost	4.9	23.5
Downwind	8.6	No *A.fumigatus* detected

Table 9 - Site B winter bioaerosol sampling results

Sample Location	Actinomycetes in air sample (cfu/m^3) x 10^3	*A. fumigatus* in air sample (cfu/m^3) x 10^3
Upwind	8.9	1.5
Top of compost silo cage, line 2	89.9	No *A.fumigatus* detected
Next to active conveyor, line 2	66.1	3.0
Inside waste reception building	70.6	No *A.fumigatus* detected
Inside maturation building	77.6	10.6
Downwind	20.1	2.3

Table 10 - Site C winter bioaerosol sampling results

Sample Location	Actinomycetes in air sample (cfu/m^3) x 10^3	*A. fumigatus* in air sample (cfu/m^3) x 10^3
Upwind	45.9	No *A.fumigatus* detected
Vessel 78	155.3	No *A.fumigatus* detected
Leachate tank	75.4	3.0
Vessel 77	63.7	No *A.fumigatus* detected
Next to entrance	55.8	No *A.fumigatus* detected
Downwind	55.8	5.0

5.3. Compost Micro-organism Counts

The compost micro-organism counts from the compost grab samples collected from sites A, B and C are presented in Table 11, Table 12 and Table 13, respectively.

For site A, the compost grab samples (green waste) with higher moisture content had lower concentrations of actinomycetes compared to compost grab samples with lower moisture content. In contrast moisture content showed no link with the concentration of *Aspergillus fumigatus*. There was generally no link between the age of compost and the concentration of micro-organisms detected in the compost grab samples. However, higher concentrations of *A. fumigatus* were detected in younger compost taken from site A.

For sites B and C, the results show no trends for the age of compost, moisture content and the concentration of micro-organisms detected in the compost grab sample. However it was not possible to enumerate any *A. fumigatus* from some of the compost grab samples, so this may have affected the results.

Table 11 - Site A Compost Sample Micro-organism Concentrations

Compost sample	Compost Age	Season	Moisture Content (%)	Actinomycetes (cfu/g – dry) x 10^3	*A. fumigatus* (cfu/g – dry) x 10^3
Incoming waste, near sampling hood left	<5 days	Summer	41.6	333.3	1038.6
Incoming waste, near sampling hood right	<5 days	Summer	50.3	136.0	2285.3
Incoming waste windrow	<5 days	Autumn	29.6	346553.5	312.8
Shredded compost	Around 19 weeks	Autumn	37.8	64147.7	26.4
Mature compost	>19 weeks	Winter	41.5	14391.3	49.8
Shredded compost	Approx. 5 days	Winter	57.9	6869.2	263.8

Note: all concentrations are the average from two samples

Table 12 - Site B Compost Sample Micro-organism Concentrations

Compost sample	Compost Age	Season	Moisture Content (%)	Actinomycetes (cfu/g – dry) x 10^3	*A. fumigatus* (cfu/g – dry) x 10^3
Bottom of compost silo cage	21 days	Summer	59.7	325.6	No *A.fumigatus* detected
Top of compost silo cage near sampling hood	1 day	Summer	54.8	202.9	No *A.fumigatus* detected
Bottom of compost silo cage	21 days	Autumn	41.7	4124.8	143.2
Top of compost silo cage	1 day	Autumn	56.7	8726.3	166.1
Bottom of compost silo cage line 2	21 days	Winter	48.8	535.7	40.2
Top of compost silo cage line 2	1 day	Winter	50.2	7373.9	20.6

Note: all concentrations are the average from two samples

Table 13 - Site C Compost Sample Micro-organism Concentrations

Compost sample	Compost Age	Season	Moisture Content (%)	Actinomycetes (cfu/g – dry) x 10^3	*A. fumigatus* (cfu/g – dry) x 10^3
Vessel 71	Around 2 weeks	Summer	32.9	2134.3	30.3
Vessel 70	Around 5 weeks	Summer	45.2	1698.5	291.4
Windrow left 1	Not known	Autumn	29.3	36903.5	No *A.fumigatus* detected
Windrow right	Not known	Autumn	23.0	50511.9	No *A.fumigatus* detected
Vessel 71	> 12 weeks	Autumn	25.2	59233.0	No *A.fumigatus* detected
Vessel 62	> 12 weeks	Winter	48.8	92156.1	20.3

Note: all concentrations are the average from two samples

The compost sample concentrations can be described as an alternative source term, as they indicate the concentrations of micro-organisms that could potentially be released from the compost. Comparing the results from the compost grab samples with the air samples shows that the concentration of bioaerosols in the compost samples is always higher than the air samples, apart from where *A. fumigatus* was not detected. The compost samples concentrations are generally 2-$\log_{10}$ higher than the air samples, although during the winter visit to site A, the concentration of actinomycetes in the compost sample was 4-$\log_{10}$ higher than in the equivalent air sample, which was the largest difference found.

5.4. Dispersion Modelling

5.4.1. Bioaerosol and Odour Emissions

The results of the SCREEN3 and ADMS 3.3 modelling of *Aspergillus fumigatus*, actinomycetes and odour are presented below (Figure 6, Figure 7 and Figure 8) for the three sites. All three graphs show that the SCREEN3 model predicts higher concentrations downwind in comparison to the ADMS 3.3 results. This is inline with other studies that have found similar results (Taha et al., 2007a). For site A, the emission with the highest concentrations at all distances downwind is *A. fumigatus*, which is the emission with the highest initial concentration at this site. Odour, which has the lowest initial concentration, has the lowest downwind concentrations. For Sites A and B, the SCREEN3 model predicts the highest ground level concentrations at 30m and 50m downwind before a steady decrease in concentration. Site C shows the same trends as site A, with the emission with the highest initial concentration (actinomycetes) having the highest concentration at all points downwind. However, site B shows that odour, which has the highest initial concentration, decreases more rapidly than actinomycetes, so that by 10m, the odour concentration is lower than the actinomycetes concentration.

Figure 6 - Downwind predicted concentrations of odour, *A. fumigatus* (Af) and actinomycetes (Ac) for site A.

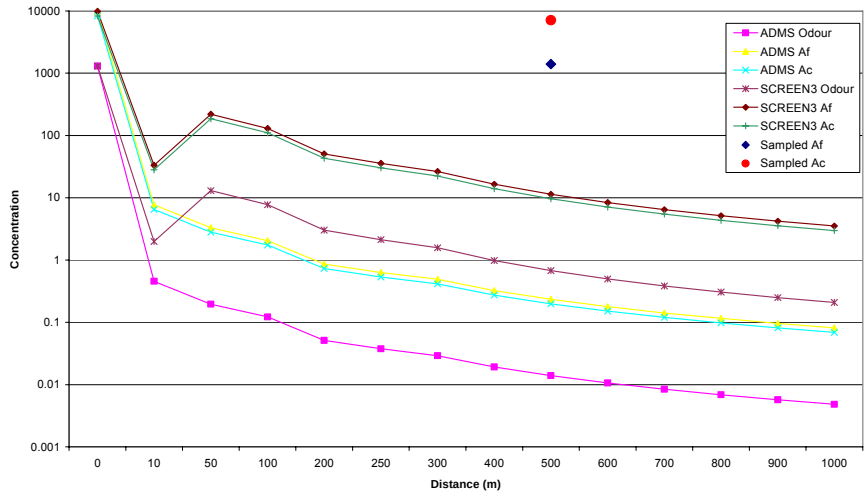


Figure 7 - Downwind predicted concentrations of odour, *A. fumigatus* (Af) and actinomycetes (Ac) for site B

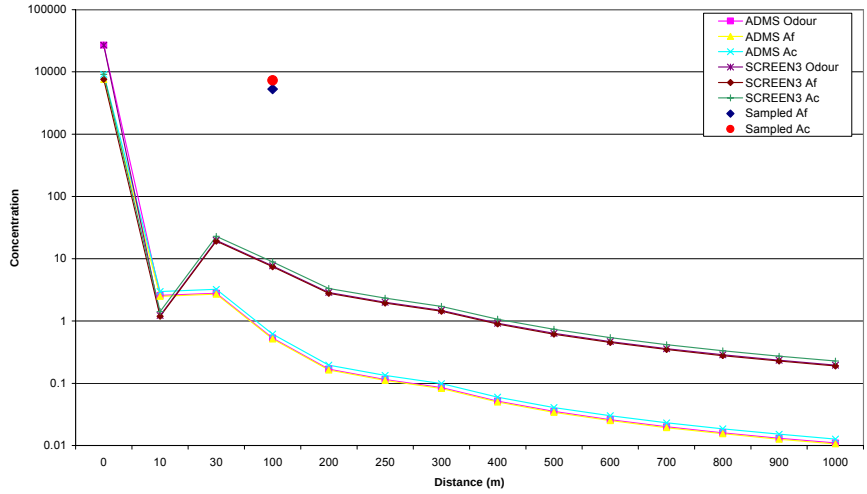
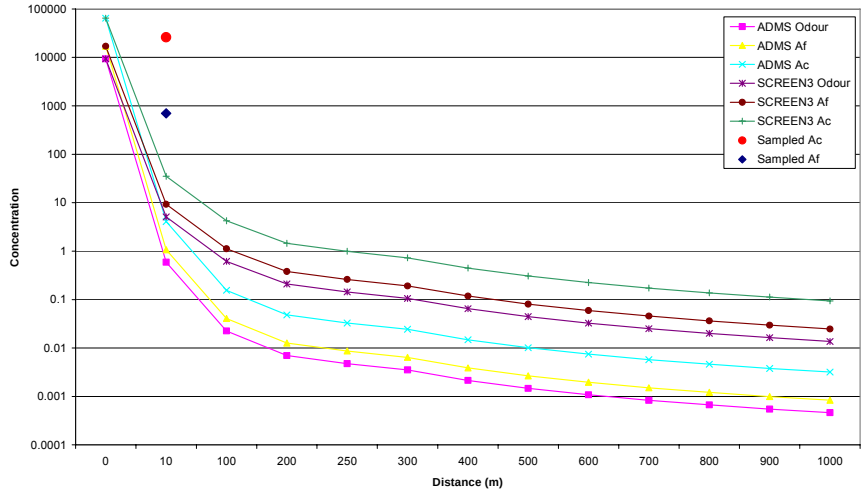


Figure 8 - Downwind predicted concentrations of odour, *A. fumigatus* (Af) and actinomycetes (Ac) for site C



These results also show that the model estimates of the concentrations of actinomycetes and *Aspergillus fumigatus* downwind from the source are much lower than those sampled downwind (shown as a red circle and blue square on the graphs). This trend holds for all sites, both micro-organisms and for both models. The SCREEN3 estimates are 2-$\log_{10}$ lower for both micro-organisms at site A and for *A. fumigatus* at site C. The SCREEN3 estimates of actinomycetes at site C and for both micro-organisms at site B were 3-$\log_{10}$ lower than the sampled concentrations. The ADMS 3.3 estimates are 4-$\log_{10}$ lower than the sampled concentrations at all sites and for both micro-organisms, apart from the A. fumigatus at site C. Unfortunately, due to the complexities associated with odour monitoring in ambient air, odour samples were not collected downwind, and so we cannot make any assumptions about downwind odour concentrations.

However, these results do not take into account any on-site agitation of the compost, which has previously been shown to be the major contribution to bioaerosol emissions from composting sites (Taha *et al*., 2005; 2006; 2007a). Furthermore, sampled downwind concentrations could be affected by other sources of bioaerosols, such as other facilities or residences located nearby, and current sampling methods do not permit source allocation of bioaerosol emissions. In addition, local conditions, such as topography and buildings may also influence downwind dispersal, and these have not been considered in these results.

5.4.2. Bioaerosol Emissions from Agitation

When sampling from agitation activities, the health and safety of the person taking the sample should always be considered. It is therefore not always possible to sample directly at source, and sometimes it is not possible to sample an activity at all. Very little agitation activities occur on site C and the activities from site B are considered in the next section, which focuses on emissions from the buildings within which all activities occur. This section therefore focuses on site A only.

The results of modelling the emissions of *Aspergillus fumigatus* and actinomycetes from the agitation activities for the autumn (compost screening) and winter (compost shredding) at site A are shown in Figure 9 and Figure 10. The autumn sampling was carried out approximately 2 m downwind of the screening activity, whilst the winter sampling was carried out approximately 10

m downwind of the shredding activity. In addition to the difference in the activities during autumn and winter, the material being agitated was also different. During autumn, the material was at the end of the composting process, while during the winter the material being shredded had just recently arrived on site and was at the beginning of the compost process. The results show that the concentrations of actinomycetes are higher than *Aspergillus fumigatus* concentrations for both winter and autumn. The autumn actinomycetes concentration is particularly high and the depletion curves shows that the concentrations remain high downwind of the site.

Figure 9 - Predicted downwind concentrations of bioaerosol emissions from agitation activities at site A during the autumn. Note: Af is Aspergillus fumigatus and Ac is actinomycetes

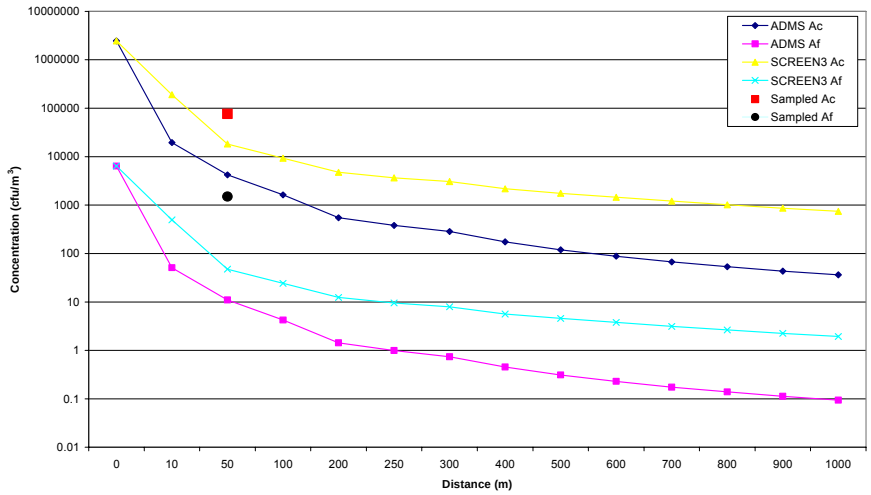
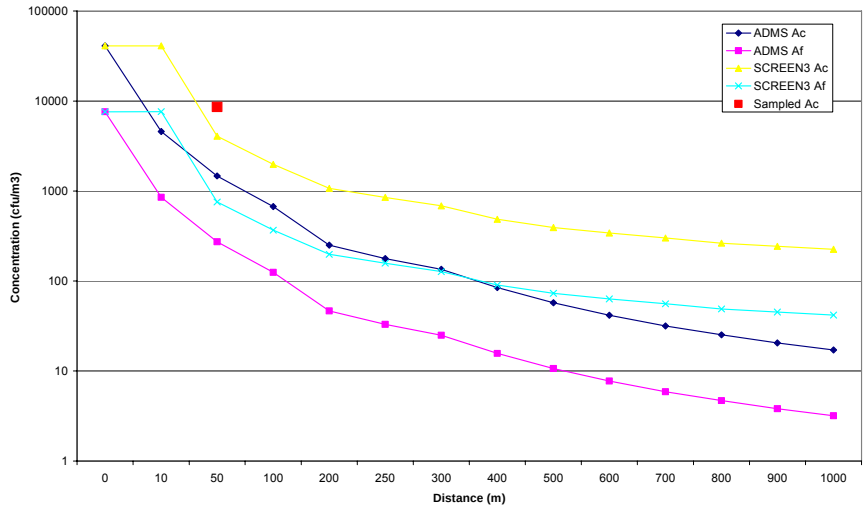


Figure 10 - Predicted downwind concentrations of bioaerosol emissions from agitation activities at site A during the winter. Note: Af is Aspergillus fumigatus and Ac is actinomycetes



In the previous section, we showed that the dispersion model results from the static emissions tended to be between 1-$\log_{10}$ and 3-$\log_{10}$ lower than the concentrations sampled downwind. For

the autumn, modelled *A. fumigatus* results are 2-$\log_{10}$ lower than sampled concentrations. As no *A. fumigatus* was detected downwind during the winter, we cannot comment on the winter results. For actinomycetes, SCREEN3 predicts downwind concentrations of the same magnitude as the sampled results during the autumn, however the ADMS 3.3 results are 1-$\log_{10}$ lower than the sampled concentrations. The winter actinomycetes downwind concentrations from both models are of the same magnitude as the sampled results. In general terms, the model predictions for the agitation activities were closer to the sampled downwind concentrations, but there was a greater difference between the model predictions and the downwind concentrations for the static sources. This suggests that the major contribution to downwind bioaerosol concentrations was from agitation activities, so when the passive sources were modelled alone, the models appear less successful at predicting downwind concentrations. It is therefore advisable to consider all possible emissions sources at a facility and to model their combined downwind concentrations where possible. The SCREEN3 model does not have the capability to do this, so the preferred model for these more detailed studies is ADMS 3.3.

5.4.3. Bioaerosol Emissions from Buildings

Composting at site C is undertaken within a series of buildings, namely the waste reception building, the processing hall and the maturation hall. The method for calculating the emissions from these buildings was described previously (Section 4.4.3). However, it was necessary to consider two scenarios with regards to these buildings. The 'best case' scenario assumes that the leakage areas, such as doors and shutters, are kept closed at all times. In reality, these areas are kept closed, apart from the periods when material is being brought in or taken away from each of the buildings. The 'worst case' scenario assumes that all the leakage areas are kept open at all times. In reality, the best case scenario most closely represents actual site practice and sampling was primarily undertaken in this conditions.

The results for the maturation building (Figure 11 and Figure 12) show the very high emissions from the building under the worst case scenario, for both dispersion models, with ADMS 3.3 predicting higher downwind concentrations than SCREEN3. Comparing the best and worst case scenarios reveals that keeping the leakage areas of the maturation building closed may lower downwind concentrations by up to 3-$\log_{10}$, as predicted by both models.

Bioaerosols were sampled approximately 50m downwind of the site boundary, which equates to about 200m downwind of the maturation building. The concentrations of *Aspergillus fumigatus* and actinomycetes sampled at this point are also shown on the graphs (Figure 11 and Figure 12). Comparing these sampled concentrations with the model predictions at this point gives some idea of how accurate the model predictions are at this point. For the worst case scenario, ADMS 3.3 over-estimates the downwind concentrations by up to 4-$\log_{10}$, while SCREEN3 underestimates the downwind concentrations by approximately 1-$\log_{10}$. For the best case scenario, SCREEN3 again underestimates the downwind concentrations by up to 4-$\log_{10}$. However, for the best case scenario, ADMS 3.3 over-estimated downwind concentrations by 1-$\log_{10}$. Given that the downwind sampling occurred when the leakage areas were closed, the best case scenario more closely represents the real life situations. We can therefore say that, as the ADMS 3.3 predictions for the best case scenario are closer to the sampled concentrations, that this model provides the prediction that is closest to reality. Given the inherent uncertainties associated with bioaerosol sampling (as discussed in the introductory section), this is a remarkably close prediction.

Figure 11 - Best case bioaerosol emissions from the maturation building (site B) for the autumn and winter, modelled as volume sources. Note: Af is *Aspergillus fumigatus* and Ac is actinomycetes

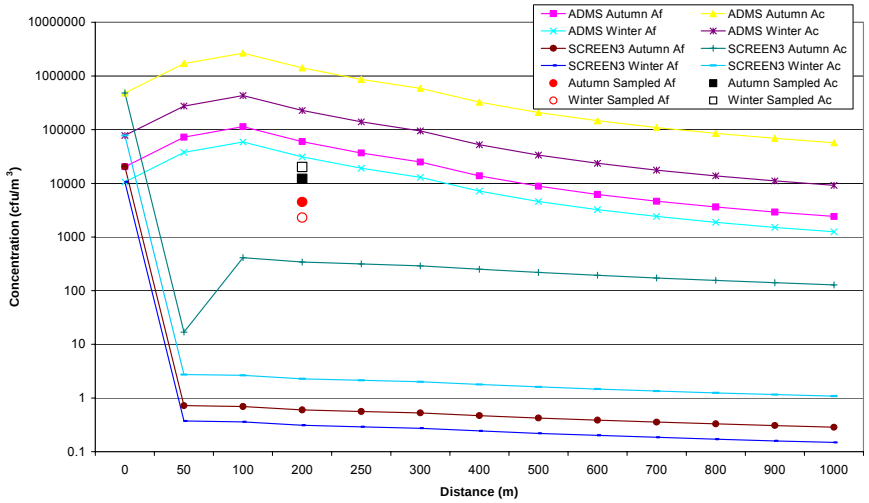
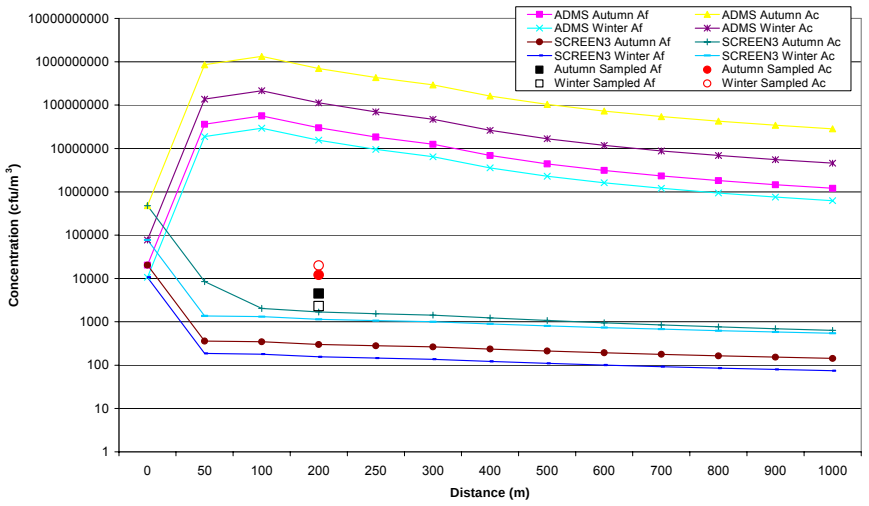


Figure 12 - Worst case bioaerosol emissions from the maturation building (site B) for the autumn and winter, modelled as volume sources. Note: Af is *Aspergillus fumigatus* and Ac is actinomycetes



The waste reception building is where the incoming material is delivered and again, the two scenarios were examined for this building. In reality, the door remains closed apart from emergency situations. The metal shutter is kept closed overnight and for most of the working day, however, the high ammonia and moisture content in the air make the current working conditions very difficult and the shutter needs to be kept open, especially in the mornings as the ammonia builds up overnight when the site is secured. There are plans to install an air exchanger/scrubber into this building to improve the situation, and after this, the leakage areas would be kept closed for the majority of the time. So the current situation is most closely represented by the worst case scenario for this building, but in the future, after the installation of the air management system, the best case scenario will most closely represent those conditions.

The modelling results for this building (Figure 13 and Figure 14) show that if the leakage areas were kept closed, this would reduce bioaerosol emissions by 1-$\log_{10}$. Interestingly, both ADMS 3.3 and SCREEN3 over-estimate the downwind concentrations, in comparison to the sampled concentrations. For the best case scenario (representing future conditions), SCREEN3 over-estimates downwind concentrations by up to 4-$\log_{10}$, whereas ADMS 3.3 only over-estimates these by up to 2-$\log_{10}$. For the worst case scenario, which is closest to the conditions on-site during sampling, ADMS 3.3 is again closer to the sampled concentrations and over-estimates these by 2-$\log_{10}$. SCREEN3 overestimates the downwind concentrations in this scenario by up to 5-$\log_{10}$, which is a significant difference.

The waste processing building adjoins the waste reception building and the conditions are fairly similar. The results from the waste processing building confirm the conclusions from the other two buildings, and so these results are not shown.

Figure 13 - Best case bioaerosol emissions from the waste reception building (site B) for the autumn and winter, modelled as volume sources. Note: Af is *Aspergillus fumigatus* and Ac is actinomycetes

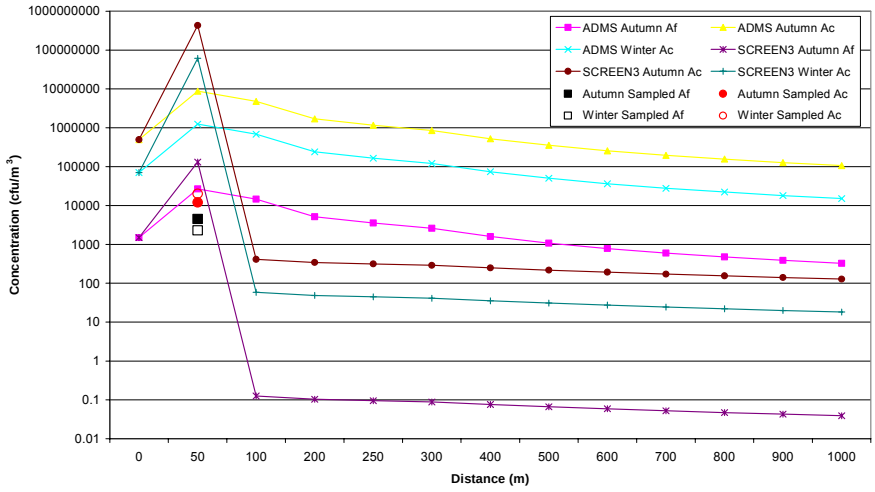
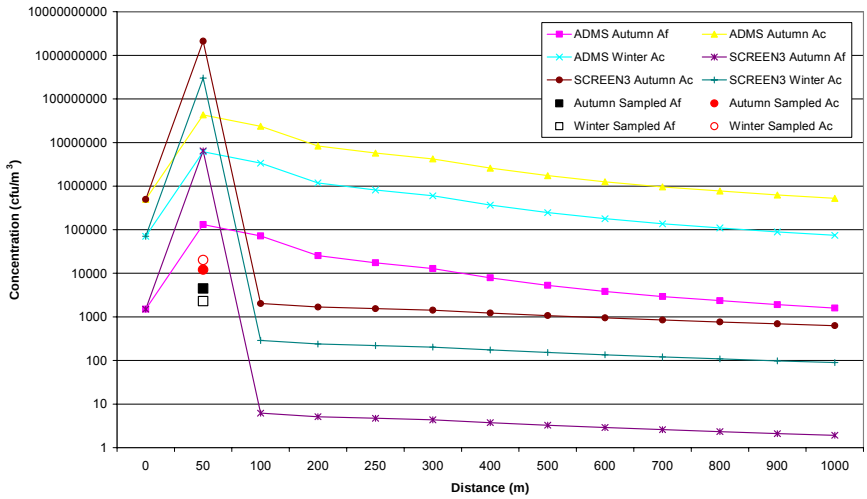


Figure 14 - Worst case bioaerosol emissions from the waste reception building (site B) for the autumn and winter, modelled as volume sources. Note: Af is *Aspergillus fumigatus* and Ac is actinomycetes



6. Discussion

6.1. Differences in Technologies and Input Material

One of the objectives of this study was to compare the different composting technologies used at the three sites, as well as the different input material that each site composts. As each site uses a different technology and accepts different input material, it is difficult to separate these two issues. Table 14 shows the range of bioaerosol emissions captured at the sites, both including the background (upwind and downwind) concentrations and excluding the background concentrations. The first result highlighted by this table, is that there is no difference between the maximums that include or exclude the background concentrations. This means that the maximum concentrations sampled were always on-site and were never background concentrations.

For actinomycetes, the majority of the on-site minimum concentrations were higher than the minimum of all samples. Therefore, the background concentrations of actinomycetes tend to be lower than the on-site concentrations. For *Aspergillus fumigatus*, the results were more mixed, with the minimum concentrations frequently measured on-site, suggesting that there are other sources of *A. fumigatus* that contribute to background measurements.

Table 14 - Ranges of bioaerosol concentrations captured at the sites during the three seasons

Site	Season	*A. fumigatus* all samples (x 10^3 cfu/m^3)		*A. fumigatus* on-site only (x 10^3 cfu/m^3)		Actinomycetes all samples (x 10^3 cfu/m^3)		Actinomycetes on-site only (x 10^3 cfu/m^3)	
		Max	Min	Max	Min	Max	Min	Max	Min
A	Summer	9.9	0.8	9.9	0.8	18.9	2.0	18.9	2.0
B	Summer	7.6	1.5	7.6	1.5	15.9	2.5	15.9	6.8
C	Summer	*1.3		*1.3		79.4	3.0	79.4	4.0
A	Autumn	45.8	1.5	45.8	2.8	2460.0	56.9	2460.0	73.5
B	Autumn	400.0	1.5	400.0	1.5	497.2	12.1	497.2	13.3
C	Autumn	17.0	0.7	*17.0		462.1	6.8	462.1	11.6
A	Winter	23.5	4.5	23.5	**4.5	93.6	4.0	93.6	4.0
B	Winter	10.6	1.5	10.6	3.0	89.9	8.9	89.9	66.1
C	Winter	5.0	3.0		*3.0	155.3	45.9	155.3	55.8

Note: "all samples" includes upwind and downwind samples.
"on-site only" excludes upwind and downwind samples.
*A. fumigatus only detected at one site during this site visit
**No A. fumigatus detected upwind or downwind

These results show that site C, the in-vessel municipal solid waste (MSW) site, has the lowest maximum *A. fumigatus* concentrations for all site visits. The concentrations of *A. fumigatus* at site A were the highest during two out of the three site visits. The highest concentrations of actinomycetes were measured at site C for two out of the three site visits, with the highest concentrations of actinomycetes measured at site A for the third visit. From these results, it is difficult to state with any confidence which technology and feedstock will consistently produce the highest bioaerosols emissions. The results do suggest that green waste windrow composting may produce higher *A. fumigatus* concentrations and that in-vessel MSW composting may result in higher actinomycetes concentrations.

In terms of the odour emissions, the animal by-products in-vessel facility (site B) had the strongest odour concentration, followed by site C, the in-vessel MSW facility. However, due to the limited number of samples that could be taken during this study, it is not possible to examine any trends in this data.

6.2. Season Differences in Bioaerosol Emissions

The results presented in Table 14 clearly show that the highest bioaerosols concentrations were measured during the autumn. The lowest concentrations were measured during the summer for all three sites. At sites A and C, the winter minimum concentration of *A. fumigatus* was the highest minimum concentration. At site B, the minimum concentrations of *A. fumigatus* were consistent throughout the different seasons. The minimum concentrations of actinomycetes measured at sites A and B were highest during the autumn site visit, but the highest minimum concentration at site C was measured during the winter. These results do suggest that higher concentrations may be found during the autumn.

6.3. Bioaerosol and Odour Emissions

One of the aims of this study was to examine the odour and bioaerosol emissions from the composting facilities. Table 15 shows the concentrations of each measured simultaneously. A simple comparison between the three sites shows that while site B had the highest odour concentrations, the lowest *Aspergillus fumigatus* and second highest actinomycetes concentrations were measured there. The bioaerosol concentrations measured at site C were both higher than at the other two sites, but the odour concentration was only the second highest measured at all three sites. However, the results for site C are for the autumn and for sites A and B, these results are for the summer. This is because the summer odour samples at site C were delivered to the odour laboratory late and so the summer results could not be validated. As discussed above, the autumn bioaerosols results were generally higher across all sites, so this may have contributed to the patterns shown here.

Table 15 - Odour and bioaerosol concentrations measured simultaneously

Emission	Site A	Site B	Site C
Odour (ou_E/m^3)	1 301	26 908	9 376
A. fumigatus (cfu/m^3)	9 900	7 600	17 000
Actinomycetes (cfu/m^3)	8 300	9 100	64 600

6.4. Context and Implications

The health effects associated with bioaerosols and their constituents have been widely reviewed (e.g. Douwes *et al*., 2003; Lacey and Dutkiewicz, 1994; Millner *et al*., 1994; Swan *et al*., 2003). *Aspergillus fumigatus* has been associated with disease such as aspergillosis and Farmer's Lung disease, and is particularly problematic for people with suppressed immune systems. Actinomycetes have been linked to allergic alveolitis and other respiratory symptoms. However, despite these associations, there is currently a lack of understanding of the dose-response relationships between bioaerosols and health effects. Although it is argued that there is a cause and effect relationship in aeroallergen exposure and allergic disease, Occupational Exposure Limits (OEL) and Threshold Limit Values (TLV) for bioaerosols have not been introduced as legal regulations anywhere in the world (van Yperen and Rutten, 1997). This

makes it complicated to predict how people may respond to the concentrations measured during this study.

A study by Wheeler et al. (2001) suggests threshold limit values for total fungi and total bacteria of 1000 cfu/m^3. Almost all the concentrations measured during this study, including the upwind and downwind concentrations, exceed this suggested limit value, for both actinomycetes and *Aspergillus fumigatus* (Table 14). The summer modelling results show that the initial high concentrations all rapidly decrease to below 1000 cfu/m^3, within 10 m of the sampling points. The dispersion modelling results from the agitation activities suggest that these high concentrations will also decrease to below the 1000 cfu/m^3 level within 250 m of the sampling sites. The emissions from the volume sources, however, are quite large, and the downwind concentrations remain high further downwind.

It is difficult to place these results within the context of other studies, due to the large variation in sampling techniques used and the limited number of published studies about emissions from in-vessel studies. The study by ADAS (2005) examined bioaerosol emissions from an in-vessel facility that accepted kerbside collected green waste and kitchen waste. Although the sampling methods were different and most of the data presented in the ADAS (2005) study was sampled at various distances downwind (25m, 75m and 125m), the concentrations of bioaerosols measured at this site were in the range of 10^2 to 10^3 cfu/m^3. The results collected during the present study are almost all higher than this range. However, a significant number of the samples collected here were collected at source for passive emissions (e.g. windrows) or as close as was safe to agitation activities (e.g. shredding), with the maximum distance sampled being 10 m downwind. The proximity to the source is most likely the cause of the higher emissions. Taha *et al*. (2006; 2007a) sampled at source at two separate composting facilities and presented concentrations of 10^3 - 10^4 cfu/m^3 for passive sources, with agitation activities typically emitting concentration of 2-$\log_{10}$ higher. The results from this study are within the same range as these previously reported at source measurements.

7. CONCLUSIONS

Sampling and dispersion modelling of bioaerosols and odour from the three different sites have shown that:

- The two in-vessel composting facilities had higher measured odour concentrations than the open windrow site. However, as they are both in-vessel, their impact on the surrounding communities might be minimised. The sampling at site C was carried out straight from the in-vessel units, before the biofilter that would control odour and bioaerosol emissions. Likewise planned installation of an exhaust management system at site B will help to control emissions at this site.

- The seasonal variation of *Aspergillus fumigatus* at all the three sites was up to 1-$\log_{10}$.

- For all sites, the concentrations of both *Aspergillus fumigatus* and actinomycetes in the autumn were higher than the concentrations detected in the summer and winter.

- For all sites and all seasons, background concentrations (such as upwind or downwind) of actinomycetes were lower than the concentrations from on-site activities and sources. For *A. fumigatus*, the results were less conclusive, with some of the on-site concentrations being lower than the background concentrations.

- Site C had the highest actinomycetes concentrations during the summer and winter. Site A had the highest actinomycetes concentrations during the autumn.

- Actinomycetes growth using the half strength nutrient agar was masked by other species of bacteria, so the compost agar proved to be a better media for actinomycetes growth.

- In general, there was no link between the age of compost grab samples, their moisture content and the concentrations of micro-organisms detected in the compost grab samples.

- The concentration of micro-organisms in the compost grab samples was always higher than in the equivalent air samples.

- The results do not conclusively show which composting technology and which input material will consistently produce the highest bioaerosols emissions.

- Dispersion modelling of the static emissions shows that both dispersion models underestimate downwind concentrations (in comparison to sampled concentrations) by 1- to 3-$\log_{10}$. For agitation activities, the model predictions of downwind concentrations were within the same order of magnitude as the sampled concentrations, suggesting that the major contribution to downwind emissions was from agitation activities.

- A comparison of the best and worst case emission scenarios revealed that sealing the leakage areas of the buildings at Site B may lower the downwind bioaerosol concentrations by up to 3-$\log_{10}$.

- The majority of sampled concentrations reduce to below the suggested threshold limit value of 1000 cfu/m^3 (Wheeler *et al*., 2001) by 250 m downwind of the sites.

- The sampled concentrations are within the same range as previously reported at source measurements (e.g. Taha *et al*., 2006; 2007a)

8. REFERENCES

ADAS/SWICEB (2005). *Bioaerosol monitoring and dispersion from composting sites*. SWICEB report, August 2005.

Ariya, P.A., and Amyot, M. (2004). *New Directions: The Role of Bioaerosols in Atmospheric Chemistry and Physics*, Atmospheric Environment, Vol. 38, pp. 1231-1232.

Composting Association (2006) *The state of composting and biological waste treatment in the UK 2004/05*. The Composting Association, Wellingborough.

Douwes, J., Thorne, P., Pearce, N., and Heederik, D. (2003), *Bioaerosol Health Effects and Exposure Assessment: Progress and Prospects*, Annals of Occupational Hygiene Vol. 47, No. 3, pp. 187-200.

Environment Agency (2001). *Agency position on composting and health effects*, Bristol, Available at http://www.environment-agency.gov.uk.

Gostelow, P., Longhurst, P., Parsons, S. A., and Stuetz, R. M. (2003). *Sampling for Measurement of Odours*, Scientific and Technical Report No. 17, IWA Publishing, London.

Jiang, J., and Kaye, R. (2001). *Sampling Techniques for Odour Measurement, Odours in Wastewater Treatment*, Measurement, Modelling and Control, IWA Publishing, London.

Lacey, J., and Dutkiewicz, J. (1994). *Bioaerosols and Occupational Lung Disease*, Journal of Aerosol Science, Vol. 25, pp. 1371-1404.

Millner, P.D., Olenchock, S.A., Epstein, E., Rylander, R., Haines, J., Walker, J., Ooi, B.L., Horne, E., and Maritato, M. (1994). *Bioaerosols Associated with Composting Facilities*, Compost Science and Utilization, Vol. 2, No. 4, pp. 6-57.

Pasquill, F. (1961) The estimation of the dispersion of windborne material. *Meteorological Magazine*, 90, 33-49.

Pollard, S., Tyrrel, S., Longhurst, P. (2004). *An Environmental Risk Management Framework for Composting Facilities in England and Wales*, Environment Agency report.

Swan, J.R.M., Kelsey, A., Crook, B., and Gilbert, E.J. (2003). *Bioaerosol Components and Hazard to Human Health*, In Occupational and environmental exposure to bioaerosols from composts and potential health effects-a critical review of published data, Research Report 130, HSE Books, U.K, pp. 15-20.

Taha M.P.M., Pollard, S.J.T., Sarkar, U. and Longhurst, P. (2005). *Estimating fugitive bioaerosol release from static compost windrows: Feasibility of a portable wind tunnel approach*, Waste Management, 24, 445-450.

Taha, M.P.M., Drew, G.H., Longhurst, P.J., Smith, R., and 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, Vol. 40, No. 6, pp. 1159-1169.

Tamer Vestlund, A., Drew, G.H., Tyrrel, S.F., Jordinson, G.M., and Pollard, S.J.T. (2007) A critical review of current issues in composting bioaerosol risk assessments. In prep.

Tammemagi, H. (1999). *The Waste Crisis-landfills, incinerators and the search for a sustainable future*, Oxford University Press, New York.

Valentin, F.H.H. and North, A.A. (1980). *Odour control – a concise guide*, Warren Spring Laboratory, Hertfordshire.

van Yperen, H.R., and Rutten, A.L.M. (1997). *Health Risks Due to Exposure to Biological Agents during Removal of Organic Waste. A Survey of Gaps in Knowledge*, Annals of Agricultural and Environmental Medicine, Vol. 4, Pages 39-43.

Wheeler P.A., Stewart, I., Dumitrean, P., Donovan, B. (2001). *Health effects of composting: a study of three compost sites and review of past data*. R & D Technical Report P1-315/TR, Environmental Agency, Bristol, UK.

APPENDICES

Appendix I Summer Sampling details

Table I.I - Site A Summer Sampling Details

Sample Location	Description of location	Temperature °C (average)	Relative Humidity (average)	Wind Speed (average)	Other Details
Upwind	Ca. 110 m upwind of site boundary	23.3	53%	1.3 m/s (ambient)	Ca. 79 m from main road (road traffic)
Wind tunnel right	On incoming waste	31.0	33%	0.6 m/s (ambient) 1.4 m/s airflow from hood	Sampling hood used. 2 compost grab samples taken.
Near houses	Near residence adjacent to site	24.4	48%	1.5 m/s (ambient)	Residences ca. 40 m from nearest windrow
Wind tunnel left	On incoming waste	26.5	46%	0.9 m/s (ambient) 1.3 m/s airflow from hood	Sampling hood used. Odour samples and 2 compost grab samples also taken.
Downwind	Ca. 70 m downwind of site activities	22.3	58%	2.1 m/s (ambient)	Livestock (sheep) ca. 250 m away

Table I.II – Site B Summer Sampling Details

Sample Location	Description of location	Temperature °C (average)	Relative Humidity (average)	Wind Speed (average)	Other Details
Upwind	Ca. 27 m upwind of maturation building	27.6	52%	0.7 m/s (ambient).	
Processing building- wind tunnel	On top of compost silo-cage	27.2	70%	0.0 m/s (ambient) 2.2 m/s airflow from hood	Odour samples and 2 compost grab samples taken. 1 day old compost
Processing building - bottom of compost silo	Bottom of compost silo-cage, 2 m from silo wall	25.5	66%	0.0 m/s (ambient)	21 day old compost. 2 grab compost samples taken.
Processing building - next to conveyor belt	Sampler ca. 0.5 m from conveyor belt	28.2	69%	0.0 m/s (ambient)	21 days old compost. Unloading activity for 9 minutes of the sampling time
Downwind	Ca. 50 m downwind of facility	25.6	56%	1.6 m/s (ambient)	Empty skips and some vehicle activity nearby

Table I.III - Site C Summer Sampling Details

Sample Location	Description of location	Temperature °C (average)	Relative Humidity (average)	Wind Speed (average)	Other Details
Upwind	Ca. 35 m upwind of site operations and ca. 160 m upwind of in-vessel compost area	13.1	76%	2.6 m/s	Sample taken within site boundaries as site surrounded by trees
Vessel 66	Samples taken from headspace inside in-vessel unit	17.6 (air outlet) 16.9 (ambient)	71% (air outlet) 57% (ambient)	0.8 m/s (air outlet) 1.1 m/s (ambient)	Compost ca. 2 weeks old. Odour samples also taken
Leachate tank	Samplers suspended from metal mesh covering leachate tank	14.0	70%	0.4 m/s	
Vessel 77	As described for Vessel 66	23.0 (air outlet) 15.5 (ambient)	100 % (air outlet) 56% (ambient)	0.9 m/s (air outlet) 1.6 m/s (ambient)	5 week old compost
Downwind	Ca. 6 m downwind of all operations	14.6	76%	0.4 m/s	Rain for first 15 mins of sample. Taken within site boundaries as site surrounded by trees

Appendix II Autumn Sampling Details

Table II.I – Site A Autumn Sampling Details

Sample Location	Description of location	Temperature °C (average)	Relative Humidity (average)	Wind Speed (average)	Other Details
Upwind *	Ca. 35 m upwind of site boundaries	12.1	90%	1 m/s	No rain. Ca. 4 m from main road (road traffic)
On incoming waste heap	On incoming waste. Samplers a few centimetres away from waste material	12.4	90%	0.5 m/s	No rain. 2 compost grab samples taken. 23 mins. into sample, truck brought in fresh waste
Next to incoming waste heap	Next to incoming waste heap. Samplers ca. 4-5 m from waste	12.6	89%	0.4 m/s	No rain. Agitation activity for first minutes of sampling (site vehicle)
Near house	Near residences	12.3	91%	0.6 m/s	Drizzling rain. Residences ca. 40 m away from nearest windrow
On screening machine	Samplers ca. 1-2 m from activity (screening, shredding, 2 vehicles)	11.5	97%	1.7 m/s	No rain. 2 compost grab samples taken
Other side of activity	Samplers ca. 30 m from activity (shredding and screening, 2 vehicles)	11.6	94%	0 m/s	Light rain for half of sampling time
Downwind	Ca. 70 m downwind of site activities and residences	11.2	96%	1.2 m/s	Rain throughout sampling. Livestock (sheep) ca. 250 m away

*Note= due to low concentrations of bioaerosols captured from this location last time, sampling point moved closer to composting activities

Table II.II – Site B Autumn Sampling Details

Sample Location	Description of location	Temperature °C (average)	Relative Humidity (average)	Wind Speed (average)	Other Details
Upwind	Ca. 27 m upwind of maturation building	14.3	66%	1.5 m/s	
Processing building - top of compost silo-cage, line 2	Samplers adjacent to compost (10 cm),1 day old compost	15.7	90%	0.0 m/s	Chicken litter in compost. 2 compost grab samples taken
Processing building - top of compost silo-cage, line 1	Samplers adjacent to compost (10 cm)	19.3	79%	0.0 m/s	1 day old compost. Chicken litter in compost
Processing building - next to active conveyor belt	Bottom of Line 1 silo-cage, conveyor belt in operation. Samplers ca. 50 cm from the belt.	19.3	58%	0.0 m/s	21 day old compost. Staff adjacent to samplers inspecting conveyor belt. 2 Compost grab samples taken. No chicken littert
Processing building - next to passive conveyor belt	Bottom of Line 2 silo-cage, conveyor belt not in operation. Samplers ca. 50 cm conveyor	19.6	56%	0.0 m/s	21 day old compost. No chicken litter
Inside waste reception building	Samplers ca. 10 m from incoming waste	20.0	67%	0.0 m/s	No traffic during sampling. Possible chicken litter in compost
Inside maturation building	Activity ca. 40 m from samplers. Waste is > 21days	20.9	65%	0.0 m/s	No chicken litter. Traffic during sampling
Downwind	Ca. 50 m downwind of facility	17.3	53%	1.2 m/s	Empty skips and some truck activity nearby

Table II.III - Site C Autumn Sampling Details

Sample Location	Description of location	Temperature °C (average)	Relative Humidity (average)	Wind Speed (average)	Other Details
Upwind	Ca. 35 m upwind of site operations and ca. 160 m upwind of in-vessel area	14.3	82%	3.4 m/s	Sample taken within site boundaries as site is surrounded by trees
Vessel 78	Samples taken from headspace inside the in-vessel unit	21.0 (air outlet) 15.5 0C (ambient)	100% (air outlet) 77% (ambient)	0.5 m/s (air outlet) 1.7 m/s (ambient)	Ca. 2-3 week old compost. Odour samples also taken
Leachate tank	Samplers suspended from metal mesh covering leachate tank	16.4	73%	0.0 m/s	More odorous compared to summer
Vessel 77	As described for Vessel 78	18.7 (air outlet) 17.7 (ambient)	97 % (air outlet) 79% (ambient)	1 m/s (air outlet) 1.9 m/s (ambient)	Ca. 4-5 week old compost
Next to windrow compost pile	Samplers suspended adjacent to compost (ca. 40 cm). Material is shredded municipal solid waste	18.9	74%	3 m/s	
Downwind	Ca. 6 m downwind of all operations	18.3	76%	0.9 m/s	Sample taken within site boundaries as site is surrounded by trees

Appendix III Winter Sampling Details

Table III.I – Site A Winter Sampling Details

Sample Location	Description of location	Temperature °C (average)	Relative Humidity (average)	Wind Speed (average)	Other Details
Upwind	Ca. 35 m upwind of site boundaries	3.3	83%	2.9 m/s	Ca. 4 m from main road (road traffic)
On finished product compost heap	Samplers a few centimetres from material	6.4	78%	1.9 m/s	2 compost grab samples taken. 50 m away from this site truck was tidying up shredded material
On shredded compost heap	Samplers a few centimetres from material	6.8	70%	0.6 m/s	The material that is just shredded is from the incoming waste compost heap. 2 compost grab samples taken from this location
Near House	Near the residences	6.8	74%	0.6 m/s	The residencies are approximately 40 m away from the nearest windrow
Shredding Activity	Samplers ca. 10 m from activity	5.0	82%	3.6 m/s	Activity from incoming waste being shredded. Around 20-30 m away, lorry is unloading gravel and stones
Next to incoming compost heap A	Samplers ca. 3 m from compost heap	7.4	73%	0 m/s	Incoming waste being shredded. Samplers ca. 10 m from unloading activity. 10 minutes into sampling, another truck brought in fresh material
Downwind	Ca. 70 m downwind of site activities and residencie	5.1	82%	2.3 m/s	Livestock (sheep) ca. 300-400 m away

Table III.II – Site B Winter Sampling Details

Sample Location	Description of location	Temperature °C (average)	Relative Humidity (average)	Wind Speed (average)	Other Details
Upwind	Ca. 27 m upwind of maturation building	9.7	81%	6 m/s	
Processing building - top of compost silo cage, line 2	Samplers adjacent to compost (10 cm)	12.0	82%	0.0 m/s	1 day old compost. No chicken litter. 2 Compost grab samples taken.
Processing building - bottom of compost silo cage, line 2 next to conveyor belt	Conveyor belt in operation. Samplers ca. 50 cm from conveyor.	11.4	76%	0.0 m/s	21 day old compost. Staff inspecting conveyor belt. 2 compost grab samples taken. No chicken litter
Inside ABP waste reception building	Samplers ca. 10 m from incoming waste	13.0	99%	0.0 m/s	No traffic. No chicken litter in compost
Inside maturation building	Activity ca. 40 m from sampler.	13.9	95%	0.0 m/s	Compost > 21days No chicken litter. Traffic during sampling
Downwind	Ca. 50 m downwind of facility	10.7	74%	2.5 m/s	Empty skips and some truck activity nearby

Table III.III - Site C Winter Sampling Details

Sample Location	Description of location	Temperature °C (average)	Relative Humidity (average)	Wind Speed (average)	Other Details
Upwind	Ca. 35 m upwind of closest site operations. Ca. 160 m upwind of in-vessel area	11.2	69%	0.0 m/s	Sample taken within site boundaries as site is surrounded by trees
Vessel 78	Samples taken from headspace of in-vessel unit	10.4 (air outlet) 8.1 (ambient)	100% (air outlet) 89% (ambient)	0.0 m/s (air outlet) 0.4 m/s (ambient)	Ca. 10 week old compost
Leachate tank	Sampler suspended from metal mesh covering leachate tank	9.1	91%	0.0 m/s	
Vessel 77	As described for Vessel 78	11.6 (air outlet) 8.8 (ambient)	100% (air outlet) 98% (ambient)	0 m/s (air outlet) 0.4 m/s (ambient)	Ca. 12 week old compost
Near entrance car park	Sample taken ca. 14 m from main building, on entrance gate near carpark	8.8	84%	1.2 m/s	
Downwind	Ca. 6 m downwind of all operations	9.0	82%	1.4 m/s	Sample taken within site boundaries as site is surrounded by trees