DISPERSION OF BIOAEROSOLS FROM COMPOSTING FACILITIES

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SUMMARY: The promotion of composting as an option for sustainable waste management has raised concerns regarding public health impacts of exposures to potentially hazardous bioaerosols. Recent source term experiments show that bioaerosol emissions are episodic and that peak emissions are related to compost agitation. The Environment Agency requires risk assessments for facilities that have sensitive receptors within 250m of their boundary. In order to improve current risk assessment methodologies, improved predictions of bioaerosol dispersal are required. Dispersion modelling has been successfully used to determine dispersion of odours from waste management. In this paper, bioaerosol concentration data measured at a composting facility is analysed in an ongoing series of model experiments, using the ADMS air dispersion model. Initial modelling results reveal that the concentrations of bioaerosols decrease rapidly with distance from the site, although under certain circumstances, it is possible that higher concentrations may still be present at 200m from the site boundary. However, dispersion models are not yet able to take into account all the properties of bioaerosols, in particular, their viability and their ability to aggregate and form clumps, which will affect the rate of dispersal. A series of experiments were designed to examine how the options within dispersion model affect the dispersion of bioaerosols and under which circumstances high concentrations may disperse to sensitive receptors. The results will be compared with bioaerosol measurements taken downwind of a composting facility, to determine the accuracy of the model predictions. This is the first stage in an attempt to design a best practice method for modelling bioaerosols.

1 INTRODUCTION

Composting has been promoted in recent years as an option for sustainable waste management, as biodegradable waste is converted into a useful product. The release of bioaerosols from composting has been extensively reviewed, along with their potential health impacts (e.g. Wheeler *et al*., 2001; Swan et al., 2003; Douwes *et al.*, 2003). Concerns over the impacts on public health from releases of bioaerosols (National Audit Office, 2002) have resulted in a need to improve the science supporting risk assessment methods used to assess the risks to communities living near composting facilities. The quality of the risk assessment is dependant on the availability and quality of the bioaerosol source term data employed (Pollard *et al.,* 2006). This data is frequently limited, in part because of the practical difficulties of microbiological analyses but also due to cost constraints.

Due to the ubiquitous nature of most bioaerosols, it can be difficult to determine the exact source of the micro-organisms. Sampling at distance from a source may therefore result in erroneous results. This has led to the use of models to predict downwind concentrations based on at or near source concentration measurements, as reviewed by Swan *et al.* (2003). Most mathematical models were developed to simulate dispersion over the medium to long range, not short ranges (< 1km). For bioaerosols in the UK, the range of interest is up to 250m as this is the trigger distance for a risk assessment, as required by the Environment Agency.

Bioaerosol dispersion will be influenced by the particle size, the emission rate, buoyancy effects, atmospheric effects and local topography. Bioaerosols range in size from 10 nm to 100 µm and have a small mass, which means that they do not settle quickly and have the potential to disperse on wind and thermal currents (Swan *et al*., 2003). Most of the current models do not take buoyancy effects of hot releases into cold air into account. In addition, recent studies (Taha *et al.*, 2006a) have shown that bioaerosol releases from composting are likely to be episodic and related to agitation activities on site. Most studies so far have failed to take this into account when modelling dispersion.

Several authors (e.g. Millner *et al*., 1980; Wheeler *et al*., 2001; ADAS/SWICEB, 2005) have assumed that bioaerosol spores are sufficiently small to allow for the use of Gaussian dispersion models, such as the Pasquill dispersion model (Pasquill, 1961), SCREEN3 (USEPA, 1995) and ADMS (Carruthers *et al.*, 1994; CERC, 2003). These methods model bioaerosols as a gas, while Fitt *et al.* (1987) used the power law and an exponential model, both of which are capable of taking the particle size into account. Furthermore, most of these studies use the Pasquill stability classes and not measured meteorological data. Despite this, there is still debate about the usefulness of any of these methods in predicting downwind concentrations of bioaerosols.

This study aims to reveal the impact of advanced dispersion modelling on downwind concentrations of bioaerosols measured at a green waste composting facility. In a series of model experiments, the impacts of the following are examined:

- the use of measured meteorological data;
- defining bioaerosols as particles (not as a gas); and
- defining bioaerosol emissions as episodic.

2 MATERIALS AND METHODS

A parallel study (Taha *et al*., 2006b) presents bioaerosol source term data from a research composting facility in South Wales, handling *ca*. 1000 m^3 of green waste per annum. The compost is processed in windrows under a 1500 m^2 building with open sides. Samples were taken from compost windrows and during agitation activities, such as turning, shredding and screening between January and March 2005. The results reveal that the age of compost has little effect on the concentrations emitted. Furthermore, the bioaerosol emissions from passive sources were in the range of 10^3 – 10^4 cfu/m^3, with releases from active sources usually 1-log higher. These emission rates were analysed using the SCREEN3 dispersion model. In this study, these bioaerosol emission rates are analysed using the ADMS dispersion model, in order to analyse the impact of using a more advanced model, with the complex options available.

The ADMS 3.3 air dispersion model (Carruthers *et al.*, 1994; CERC, 2003) is an advanced steady state, Gaussian-like dispersion model, capable of modelling continuous plumes, short duration releases and transport over complex terrain. The model simulates point, line, area and volume sources, and can estimate pollutant concentrations at a number of user defined receptors. The model has been shown to perform in a comparable manner to similar new generation models (Hanna *et al.*, 2000). The model parameters used for each of the three experiments are described below.

2.1 The impact of meteorological data

The bioaerosol emission rates used have been reported elsewhere (Taha *et al.*, 2006b) and have been used to model dispersal with the SCREEN3 model and with ADMS 3.3 using the Pasquill stability classes. In these experiments, ADMS 3.3 was run with hourly observed meteorological data provided by the UK Meteorological Office, to produce a long term average for the site. The windrows were modelled as area sources and the agitation activities were represented by point sources within the model. These different sources were modelled together to provide the combined emissions from the study site. The full model parameters are shown in Table 1. The results are compared to the results based on the Pasquill stability classes.

Table 1: Model parameters used for the ADMS 3.3 modelling

Parameter	Active emissions (agitation activities)	Passive emissions (windrows)
Source type	Point	Area
Source release height	0m	2m
Source length	-	80m
Source width	-	20m
Receptor height	1.8m	1.8m
Stack height	3m	-
Stack diameter	3m	-
Roughness length	0.1m	0.1m
Stability class	A	A
Exit velocity	0.2m	0.3m
Stack exit temperature	15°C	15°C
Buildings	No	No
Complex terrain	No	No

2.2 Bioaerosols as particles

A second series of model experiments were undertaken to examine the influence of dry deposition and of modelling bioaerosols as particles in ADMS 3.3, using the bioaerosol emission rates, meteorological data and model parameters described above. The dry deposition modelling was carried out using particle size and terminal velocity as deposition parameters (Table 2). The terminal velocity parameter is determined by the gravitational settling of the particles (CERC, 2003). These parameters were defined based on the research of Lacey and Dutkiewicz (1976) on the isolation of actinomycetes and fungi from hay using a sedimentation chamber.

Following the modelling of single particles with dry deposition, the particles were then modelled together as aggregates. Several different pollutant types were defined in terms of their deposition parameters with their mass fraction adding up to 1 to represent a whole cluster. Tham and Zuraimi (2005) have reported bacteria to occur as aggregates when they occurred at sizes between 3 and 7.5 µm. Ho *et al.* (2001) has reported bacteria, which was between the sizes of 2.5 and 4 µm contained 4.5 viable spores. The modelled aggregates were therefore defined to represent these values (Table 2).

Table 2: Particle size and terminal velocity used to model bioaerosols as particles

Species	Terminal velocity (m/s)	Particle size (m)	Number of spores in aggregate
A.fumigatus	0.00029	0.0000031	3
Thermoactinomyces vulgaris	0.00001	0.00000058	4 or 8

3 RESULTS AND DISCUSSION

3.1 The impact of meteorological data

Figures 1 and 2 demonstrate the impact of using hourly meteorological data on the long term average concentration of *Aspergillus fumigatus* and actinomycetes respectively. In comparison to model concentrations based on three of Pasquill's stability classes (very unstable, neutral and very stable). The graphs show that under very stable conditions, ground level bioaerosol concentrations are higher than the other stability classes, by close to one order of magnitude. The use of the meteorological data results in lower ground level concentrations than all the stability classes. According to Environment Agency guidance (Environment Agency, 2004), a typically acceptable background concentration is 10^3 cfu/m^3, and a risk assessment is required for a facility that has a sensitive receptor within 250m of its boundary. Under very unstable conditions, *A. fumigatus* has reduced to below this level by 50m, while actinomycetes only reduce to below the 10^3 cfu/m^3 value by 100m. For neutral conditions these distances decrease to 40m for *A. fumigatus* and remains at 100m for actinomycetes. Under very stable conditions the concentrations remain higher for longer, so *A. fumigatus* only reduces to below background levels by 200m and 300m for actinomycetes, which is beyond the Environment Agency risk assessment threshold. For the experiments using the hourly meteorological data, the concentrations of both *A. fumigatus* and actinomycetes are below the 10^3 cfu/m^3 value from 10m. These results suggest that studies based only on the Pasquill stability classes (e.g. Swan *et al.*, 2003; ADAS, 2005) will present more conservative results than those where hourly observed meteorological data is used.

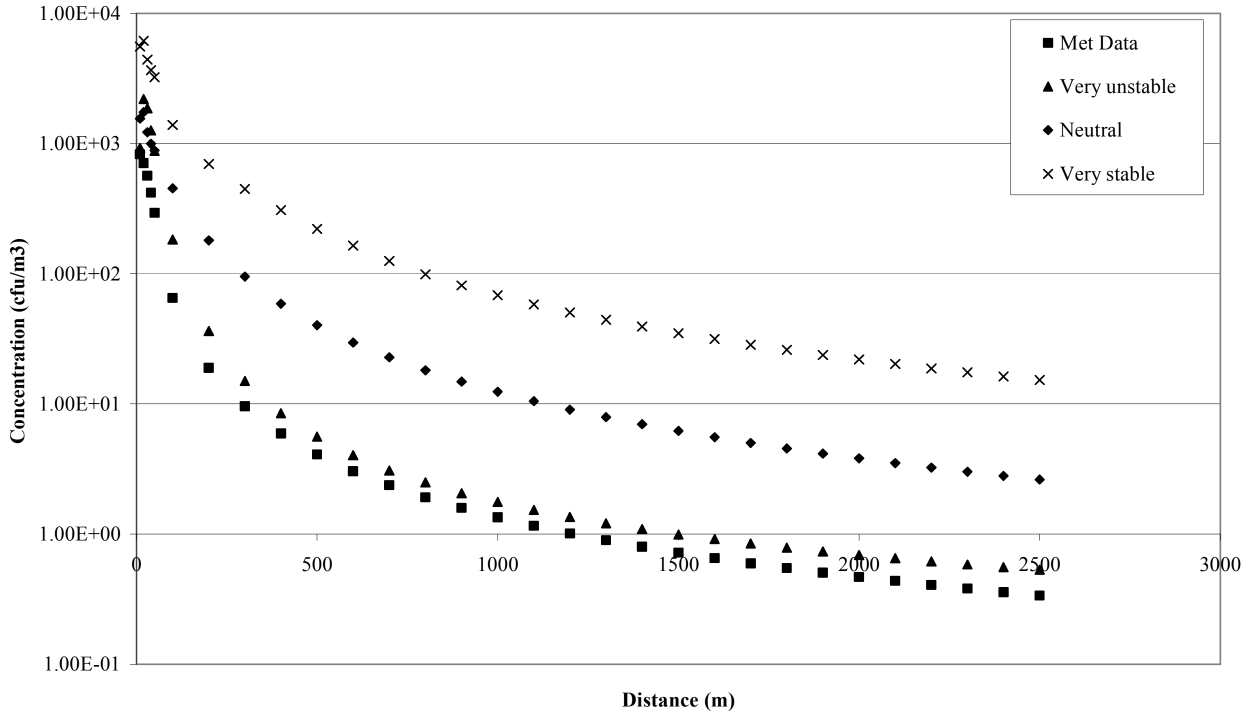

Figure 1. The modelled impact of meteorological data on downwind dispersal of *Aspergillus fumigatus*.

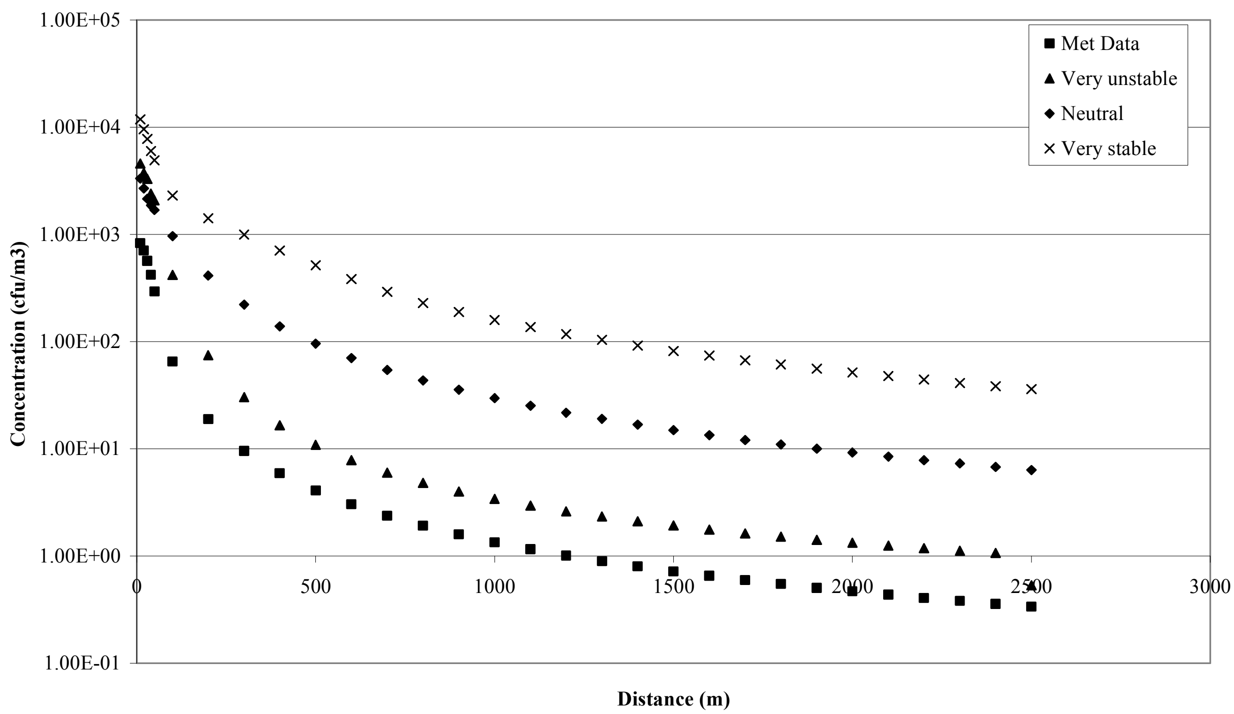

Figure 2. The modelled impact of meteorological data on downwind dispersal of actinomycetes.

3.2 Bioaerosols as particles

Bioaerosol particle size and agglomeration play an important role in the aerodynamics of bioaerosol spores when modelling their dispersion. In addition, the bioaerosol particle size determines the transport of the spore in the human respiratory system and affects the efficiency of bioaerosol samplers such as impactors (Reponen *et al.*, 1998; Venkataraman and Kao, 1999; Trunov *et al.*, 2001; Agranovski *et al*., 2004).

The results for *A. fumigatus* (Figure 3) show that modelling the spores as particles results in an increased drop out from the plume, shown as lower ground level concentrations on the graph (in comparison to the results using the meteorological data and stability classes). The modelled concentration when *A. fumigatus* is represented as particles decreases to below 10^2 cfu/m^3 by 50m from source, whereas the concentration when *A. fumigatus* is modelled as a gas is still above 10^3 cfu/m^3 at 50m. When dry deposition is used within the model, the deposition velocity is taken into account and results in an even more rapid drop-out of the *A. fumigatus* spores. Incorporating the potential for the spores to agglomerate has the opposite effect, with the agglomeration concentrations consistently between the particle and deposition concentrations. For example, at 50m the particle concentration is approximately 96 cfu/m^3, the deposition concentration is approximately 70 cfu/m^3, and the agglomeration concentration is approximately 88 cfu/m^3. These results all support our previous research (Taha *et al.*, 2005; 2006a) where we showed that bioaerosol concentrations are likely to decrease below acceptable levels before the Environment Agency 250m risk assessment threshold.

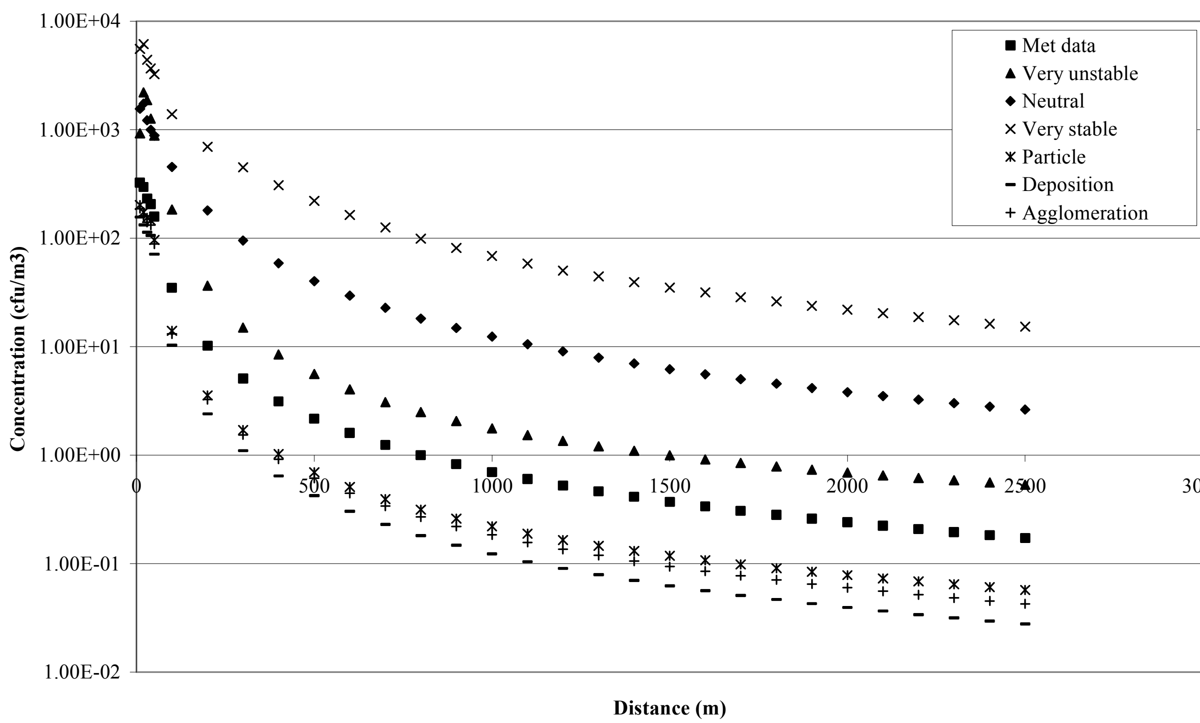

Figure 3. The impact of modelling *A. fumigatus* spores as particles, with dry deposition and agglomeration.

In contrast to the results presented for *A. fumigatus* spores, the results for actinomycetes (Figure 4) show less of a distinction between the different model experiments. Modelling actinomycetes as particles does result in a decrease in the concentration (1.7 x 10^2 cfu/m^3 at 50m) in comparison to the results when actinomycetes is modelled as a gas (2.9 x 10^2 cfu/m^3 at 50m). However, the impact of modelling with dry deposition and agglomeration has little or no effect in comparison to the results as particles. This is most likely due to the very small terminal velocity and particle size used to represent actinomycetes (Table 2).

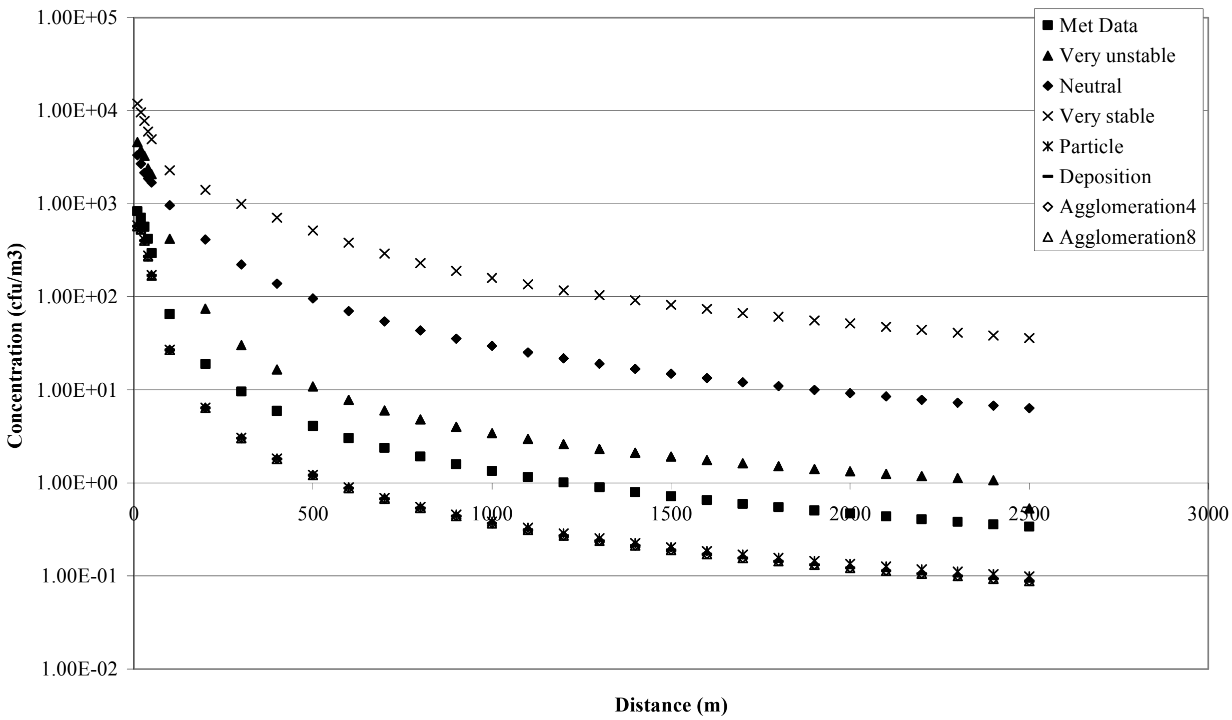

Figure 4. The impact of modelling actinomycetes spores as particles, with dry deposition and agglomeration. (Note: the numbers 4 and 8 in the agglomeration experiments refer to the number of spores in the aggregate).

Lacey and Dutkiewicz (1976) have reported higher sedimentation rates for bacteria than *Aspergillus fumigatus* and actinomycetes. They argued that this was possibly because bacteria occurred as aggregates. The results presented here show the influence of particle size on downwind concentrations of bioaerosols. For the larger *A. fumigatus* spores, the impact of dry deposition and agglomeration were visible, but for the smaller actinomycetes spores, dry deposition and agglomeration made little or no impact. In order to fully validate these results, accurate information on bacteria and fungi particle sizes would be needed. In addition, futher field studies should attempt to examine the tendency of bioaerosols to form aggregates.

4 CONCLUSIONS

Using previously published source term emissions of bioaerosols, we have estimated downwind bioaerosol concentrations using the ADMS 3.3 dispersion model. We have previously concluded that the simpler SCREEN3 model produces more conservative estimates of downwind concentrations than the more advance ADMS3.3 (Taha *et al.*, 2006b). The results presented here reveal that many of the methods previously used will result in these conservative predictions. In particular, we have shown that:

- the use of hourly meteorological data in dispersion modelling provides less conservative estimates of downwind bioaerosol concentrations;
- modelling bioaerosols as particles and with dry deposition results in lower ground level concentrations than when bioaerosols are modelled as a gas;
- the impact of bioaerosol agglomeration is only likely to be seen in modelled concentrations when larger spore particles are modelled.

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