Mushroom Biology and Mushroom Products, Royse (ed.) © 1996 Penn State Univ. ISBN 1-883956-01-3

Modeling of Odor Generation and Transport from Mushroom Composting Facilities

Paul Heinemann and Dirk Wahanik
Department of Agricultural and Biological Engineering, The Pennsylvania State University, University Park, PA, 16802 USA. E-mail address: hzh@psu.edu

ABSTRACT: An odor source generation model and an odor dispersion model were developed to predict the local distribution of odors emanating from mushroom composting facilities. The odor source generation model allowed for simulation of various composting wharf configurations and odor source strengths. This model was linked to a Gaussian plume diffusion model that predicted odor dispersion. Dimethyl disulfide production at a rate of 1760 mg/hr was simulated by the source generation model and four different atmospheric conditions were analyzed to demonstrate the effect of wind speed, atmospheric stability, and source generation on the dispersion of this odor producing compound. Detectable levels of dimethyl disulfide were predicted to range from less than 100 m from the source during very unstable conditions to almost 5000 m during very stable conditions.

1 INTRODUCTION

Odors from agricultural operations have become a concern to neighboring residents in many locations. As housing developments encroach on what has been traditionally agricultural regions, complaints and calls for government regulation have increased. The composting of mushroom substrate has the potential for creating odors if the compost piles are not managed properly. An understanding of the odor generation and how atmospheric conditions can affect the transport of the odors can help composters alter their management strategies to reduce the impact on neighboring communities. This paper describes mushroom compost odor source generation and odor transport and dispersion modeling. The objectives of this work were to: 1) develop an odor source generation model;

2) develop an odor dispersion model that would be linked with the odor source generation model; 3) verify the source and dispersion models.

Table 1. Sampling of odor-producing gasses produced by mushroom composting (Condensed from Miller and Macauley, 1988, and Derikx *et al.* 1990).

Compound	Boiling point (°C)	Threshold odor (nL/L)	Odor index
Ethanol	20.8	2	NA
Ammonia	-33.4	37	1.67×10^5
Hydrogen sulfide	-60.7	1.1	1.70×10^7
Carbon oxysulfide	-50.2	NA	NA
Dimethyl sulfide	37.3	20	2.76×10^6
3-dimethyl disulfide	109.7	NA	NA
Methanethiol	6.2	1.1	5.33×10^7
Ethanethiol	25	0.016	NA

NA = Not available

2 METHODOLOGY

2.1 *Odor sources*

Miller and Macauley (1988) analyzed odor-contributing gasses produced by mushroom compost. The compounds producing mushroom compost odors were found to be primarily gaseous (Table 1). The threshold odor is the level at which humans can detect a particular compound. Once the amount of gas being produced by the compost is known, it can be converted into odor units by dividing concentration of a given gas by its corresponding odor threshold. The sulfide and thiol compounds have low odor thresholds and therefore can be present in small quantities and still be detectable. Derikx *et al.* (1990) identified and quantified several sulfur compounds emitted from phase I mushroom compost stacks. During the first ten days of composting dimethyl sulfide is the most abundant sulfurous compound produced and during the final five days methanethiol, carbon disulfide and dimethyl disulfide become the most abundant compounds produced (Table 2). Derikx *et al.* (1991) found that the production of some sulfurous compounds is temperature dependent.

2.2 *Model development*

A source generation model was developed and linked to a dispersion model to predict movement of odors from composting wharves. The source model determined the odorous compound emission rate from a composting wharf, and the dispersion model used this emission rate and meteorological data to predict an odor plume. The model was verified using a composter survey to compare the results of the models with casual observations at composting operations.

Table 2. Emissions of volatile sulfur compounds during production of the compost used as a substrate in mushroom cultivation (Derikx *et al.* 1990).

Composting period (days)	Mean air flow rate ($m^3/m^2/hr$)	Concentration (micromol/kg [fresh wt] of product) of:						
		H_2S	COS	CS_2	CH_3SH	$(CH_3)_2S$	$(CH_3)_2S_2$	$(CH_3)_2S_3$
0-3.5	4.56	0.3	1.1	2.0	1.6	6.9	0.6	0.7
3.5-7.0	3.97	0.3	1.3	1.7	0.7	6.8	1.3	1.0
7.0-10.5	4.93	11.2	9.8	2.9	10.2	12.0	1.3	0.8
10.5-14.0	7.19	11.1	11.9	24.3	19.8	13.4	26.9	1.6

The source model and the dispersion model were combined and simulated by a computer program. The program was flexible to allow inputs representing different mushroom composting conditions. The inputs into the source and dispersion program were the source characteristics (size and strength) and specific meteorological conditions. The output from the program was a prediction of an odor plume. Source characteristics were held constant, and the effect of different meteorological conditions were compared and verified with the composter survey.

2.2.1 *Source model.* The source model simplified the composting wharf into a form usable by the dispersion model. It reduced the overall odorous compound production of the entire wharf into line of point sources that represented all odor emissions from the composting wharf. The source characteristics were the source size, the number of odor sources on the wharf, and the odor emission rate from each of these sources. The wharf was assumed to be rectangular, oriented east-west and north-south. The user provided the wharf width (the distance from east to west) and length (the distance from north to south). For example, the sample wharf shown in Fig. 1 has a width of 18 m and a length of 20 m. It contained four parallel 2 m X 20 m piles separated by 2 m. These sources are measured in square meters and are also oriented east-west and north-south. The user provides the origin (the most north-westerly point of the source with respect to the wharf origin), width and length of each rectangular source. The odor emission rate is also provided by the user and is given in $\mu g \ hr^{-1} \ m^{-2}$.

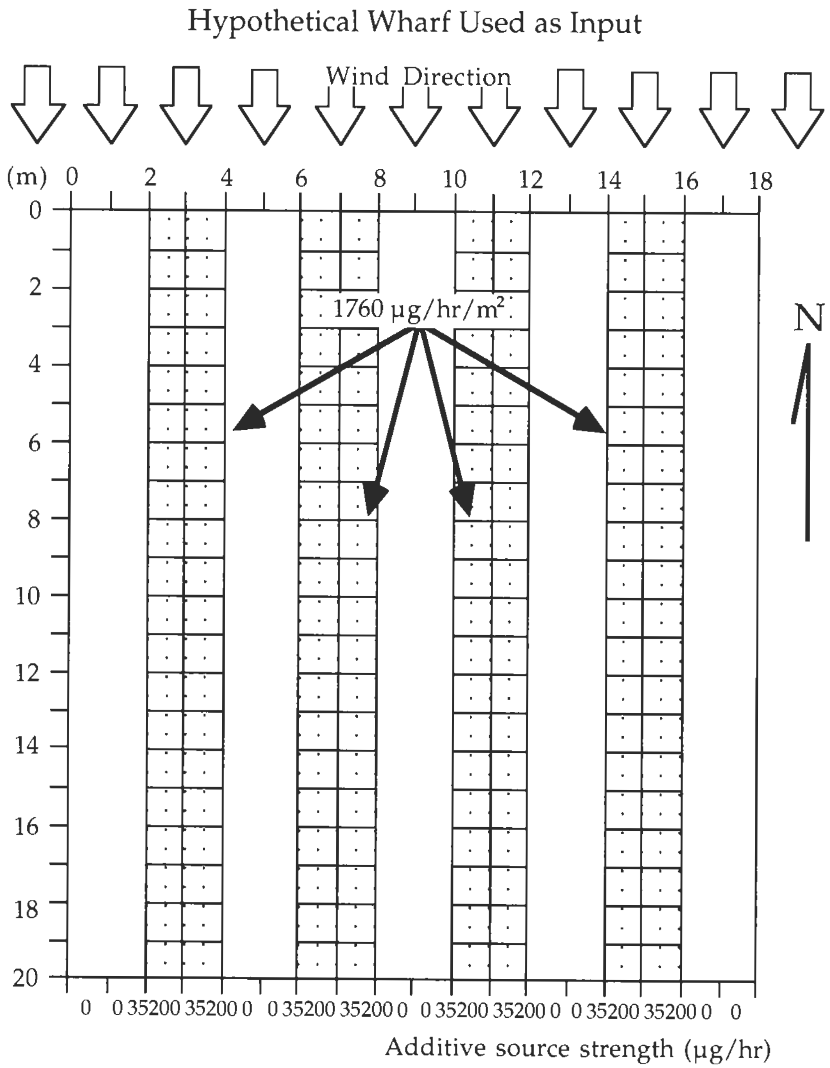

Figure 1. Hypothetical wharf used as the source for the computer model.

2.2.2 *Dispersion model.* The odor dispersion model uses the finite line source from the source model to predict the concentrations of odorous gasses downwind of the wharf. The odor dispersion model is based on a Gaussian plume model. It is easy to use, widely accepted, and suitable for comparison of different conditions (Gassman 1992). The Gaussian plume assumes that odor concentration is highest along the centerline of the wind direction (Panofsky and Dutton 1984). The width and height of these normal curves are governed by the atmospheric stability. The Gaussian model is a good tool when making comparisons but it is not reliable for absolute values (Gassman 1992). This model is used for comparative results in this project.

Table 3. Key to Pasquill Categories (Panofsky and Dutton 1984).

Wind speed	Day			Night	
(at 10 m)	Incoming solar radiation			Thinly overcast or ≥ 4/8 cloud	Clear or ≤ 3/8 cloud
(m/sec)	Strong	Moderate	Slight		
< 2	a	a-b	b		
2 to 3	a-b	b	c	e	f
3 to 5	b	b-c	c	d	e
5 to 6	c	c-d	d	d	d
> 6	c	d	d	d	d

Note: Assume the neutral class, d, for overcast conditions during day or night.

Atmospheric stability is described by categories, known as the Pasquill stability classes, which are meteorological conditions grouped from 'a' through 'f'. The categories are determined by time of day, cloud cover, and surface wind speed (Table 3).

3 RESULTS AND DISCUSSION

The computer model was run to compare the dispersion of odors under varying atmospheric conditions. Additionally, fourteen mushroom growers responded to a survey concerning composting odors and meteorologi-

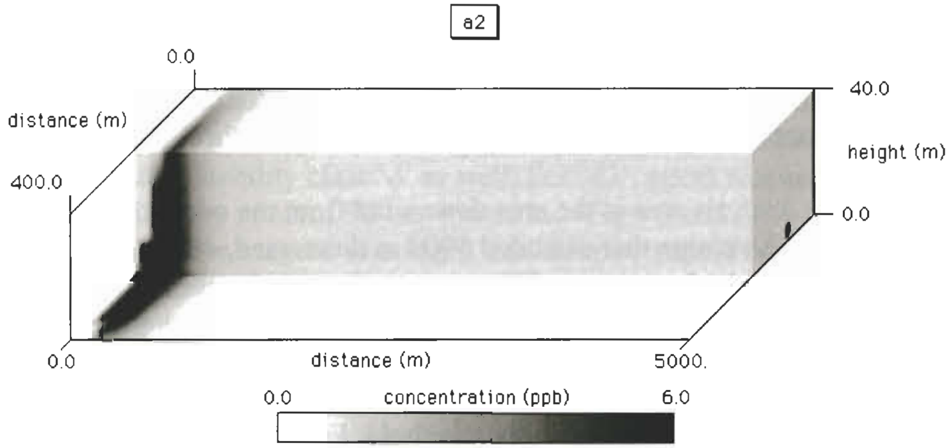

Figure 2. Plume profile for Pasquill stability class 'a' and wind speed at 2 m s^{-1}.

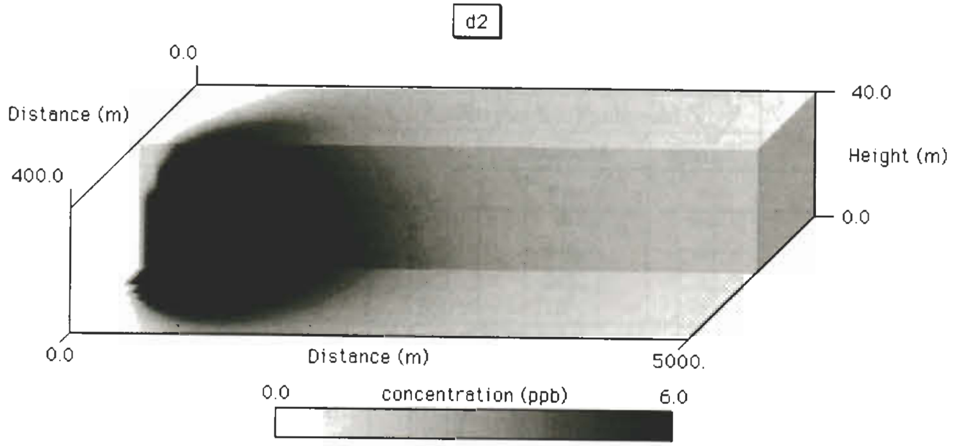

Figure 3. Plume profile for Pasquill stability class 'd' and wind speed at 2 m s^{-1}.

cal conditions conducive to odor dispersion. This section describes some sample model results and comparisons to the grower surveys.

The wharf configuration shown in Fig. 1 was simulated. Dimethyl disulfide was chosen for analysis, with a source strength of 1760 μg m^{-2} hr^{-1}. At the end of each row, the additive source strength was 35200 μg hr^{-1} (1760 μg m^{-2} hr^{-1} x 20 m^{2}).

Four different atmospheric conditions were simulated. Three incoming radiation conditions were chosen to demonstrate the effect of atmospheric stability on the dispersion of odor: 1) strong incoming radiation (sunny, unstable day), 2) weak radiation (overcast, near neutral days and nights), 3) little to no incoming radiation (clear, stable nights). Wind speeds of 2 m s^{-1} and 5 m s^{-1} were chosen. The conditions to be tested were Pasquill stability category 'a' at 2 m s^{-1} for sunny days, 'd' at 2 m s^{-1} and 'd' at 5 m s^{-1} for overcast days, and 'f' at 2 m s^{-1} for clear nights. From this point these conditions will be abbreviated as 'a2', 'd2', 'd5', and 'f2'.

The analysis area is the area downwind from the odor source to be investigated. A volume that extended 5000 m downwind, 400 m crosswind (with the source in the center at 200 m), and 40 m in elevation was determined for the analysis area. Graphical visualizations of the odor dispersion plumes are shown in Figures 2 through 5. All concentrations that were at or above the odor threshold values are shown as black. The other shades represent concentrations below odor threshold. For dimethyl disulfide the odor threshold value was 6 ppb (Derikx *et al.* 1991). After the model was run, the general results were verified using the composter survey.

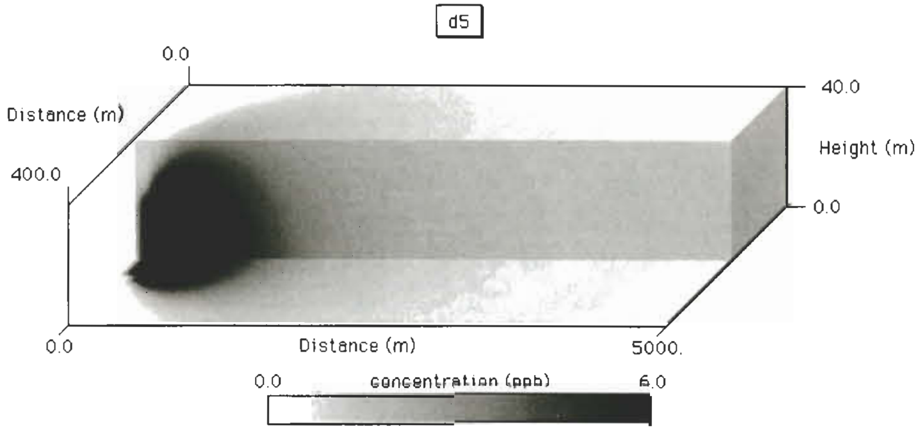

Figure 4. Plume profile for Pasquill stability class 'd' and wind speed at 5 m s^{-1}.

Comparison of the different stability classes demonstrates the amount of influence the atmosphere has on odor dispersion. For the highly unstable 'a2' conditions, gasses are dispersed below threshold within 400 m of the source. In real conditions, the odors are often not detectable much beyond the composting facility under these unstable conditions. Odors are more likely to be detected outside the composting facility under overcast, near neutral conditions. According to the model, the furthest detectable odors would be found 1500 m from the source with a wind speed of 2 m s^{-1} under these conditions. Detectable odor levels can be found furthest from the source when extremely stable conditions are present, such as evenings and early mornings. With a wind speed of 2 m s^{-1}, odors in 'f2' conditions can reach 4400 m downwind of the source. Stable conditions with low winds are the most conducive to odor events.

According to the model, compost odors are dispersed more quickly with higher wind velocities. Higher winds are conducive to greater mixing and the model results show this. The effect of wind was noticeable with the near neutral stability class 'd' as well. For 'd2', odors reached 1500 m, while for 'd5' they reached 900 m downwind (Figs. 3 and 4).

Fourteen managers who make mushroom compost responded to the survey. The survey asked questions about under which conditions they felt that the odors were strongest and weakest. The survey results were subjective, but some valuable information can be ascertained from them. The majority of respondents stated that humidity was a factor in compost odor and half mentioned heat also. It is possible that the humidity may also reflect overcast conditions. In this case, the model results are supported by the statements of the composters. This conclusion can be

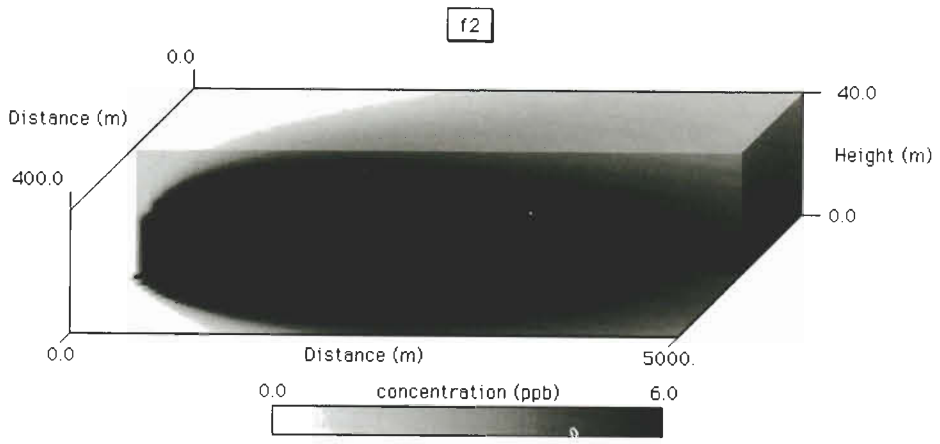

Figure 5. Plume profile for Pasquill stability class 'f' and wind speed at 2 m s^{-1}.

further supported by the fact that none of the composters mentioned sunlight as a factor that increases odors and that three of the composters specifically mentioned rain or fog to be factors that increased odor. Additionally, four of the composters stated that dryness was a factor that reduced odors. Although this may be interpreted as low microbial activity causing the odor reduction, it could also imply clear, sunny days are less conducive to odor events. The fact that two composters noticed that evenings and early mornings were times of strong odors was encouraging. This supports the model findings that higher stability would lead to stronger odor events. Another interesting point is that of wind speed. Four of the composters mentioned that stillness was a factor for strong odors. This supports the model results which demonstrated that lower wind speeds are more conducive to odor events.

4 CONCLUSIONS

Although the emission, transport, and dispersion of dimethyl disulfide was predicted, it is important to remember that these are not absolute values. Due to the nature of the Gaussian method, it is recommended for comparing plumes under different atmospheric conditions. The Gaussian model predicts concentrations when the sampling time is much greater than the travel time of a particular emission, and therefore has a high degree of averaging. Instantaneous measurements may result in values

that differ considerably from model predictions. The predicted plumes were supported through an understanding of atmospheric science and the survey results.

The source model predicted odor generation from a composting wharf. However, the additive assumption that the model uses to create a point source set of finite length could not be verified. When determining a concentration 500 m away from a source that may be 50 m wide one should prefer to use a 50 m point source set than a single point source to predict that concentration. In other words, the point source approach should not be used for a large source when the analysis area is within close proximity. Although the additive assumption makes sense, it still needs to be scientifically validated.

The odor dispersion model was successfully linked to the source model. The plume concentration values appear to be reasonable, but could be made more accurate with the incorporation of complex terrain effects.

REFERENCES

Derikx, P. J. L., H. J. M. Op Den Camp, C. van der Drift, L. J. L. D. van Griensven, and G. D. Vogels. 1990. Odorous sulfur compounds emitted during production of compost used as a substrate in mushroom cultivation. Appl. Environ. Microbiol. 56:176-180.

Derikx, P. J. L., F. H. M. Simons, H. J. M. Op Den Camp, C. van der Drift, L. J. L. D. van Griensven, and G. D. Vogels. 1991. Evolution of volatile sulfur compounds during laboratory-scale incubations and indoor preparation of compost used as a substrate in mushroom cultivation. Appl. Environ. Microbiol. 57:563-567.

Gassman, P. W. 1992. Simulation of odor transport: A Review. 1992. ASAE paper #92-4517.

Miller, F. C., and B. J. Macauley. 1988. Odours arising from mushroom composting: A Review. Australian J. Expt. Agric. 28:553-560.

Panofsky, H. A., and J. A. Dutton. 1984. Atmospheric turbulence. NY: John Wiley and Sons.