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Analysis of particle-borne odorants emitted from concentrated animal feeding operations

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HIGHLIGHTS

- 57 non-sulfur-containing odorants were identified and quantitated.
- Indole, phenylacetic acid and (*E*,*E*)-2,4-decadienal were most odor-contributing.
- TSP and PM_{10} odorant composition varied significantly with animal operation type.
- Season had a significant effect on TSP and PM_{10} odorant composition.
- PM_{10} contained significantly higher odorant concentrations than TSP.

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ABSTRACT

Airborne particles are known to serve as a carrier of odors emanating from concentrated animal feeding operations (CAFOs). However, limited quantitative data about particle-borne odorants preclude an accurate assessment of the role of particles in odor transport. This study collected total suspended particulates (TSP) and PM_{10} (particles with aerodynamic diameter smaller than 10 μm) at the air exhaust of eight types of CAFOs (swine: farrowing, gestation, weaning, and finishing; poultry: manure-belt layer hen, tom turkey, chicken broiler, and cage-free layer hen; in total 20 animal buildings) in multiple seasons, and examined the variability in particle odorant composition with animal operation type, season, and particle size. Fifty-seven non-sulfur-containing odorants were identified and quantitated, including carbonyls, alcohols, acids, phenols, and nitrogen-containing compounds. They in total accounted for 2.19 ± 1.52% TSP and 4.97 ± 3.25% PM_{10} mass. Acetic acid and ethanol were most abundant but less odor-contributing than phenylacetic acid, indole, dodecanoic acid, and (*E*,*E*)-2,4-decadienal, as determined by odor activity value. Particle odorant composition varied significantly with animal operation type, season, and particle size. The TSP and PM_{10} samples from swine gestation buildings, for example, showed distinctly different odorant compositions than those from tom turkey buildings. The summer TSP and PM_{10} samples contained in general lower concentrations of short-chain fatty acids but higher concentrations of long-chain fatty acids, aldehydes, and short-chain alcohols than the winter samples. Compared to TSP, PM_{10} samples from different types of CAFOs shared a more similar odorant composition, contained higher odorant concentrations per mass of particles, and accounted for on average 53.2% of the odor strength of their corresponding TSP samples.

1. Introduction

Odors from concentrated animal feeding operations (CAFOs) can be a nuisance to neighboring communities and may result in adverse health effects (Schiffman et al., 1995; Thu et al., 1997; Schiffman, 1998; Schiffman et al., 2000; Zhu, 2000). As more residential communities are being built near animal farms, there has been increasing complaints against CAFO odors. Although currently there is no federal regulation in the U.S., some states and cities have enacted air quality standards for odors in the ambient air (Mahin, 2001). To address the upcoming challenges in odor emission control, a quantitative analysis of CAFO odors becomes urgently needed.

Odor can be analyzed by various techniques such as scentometry, olfactometry, gas chromatography (GC), infrared spectroscopy (IR), and electronic nose. Among them, gas chromatography–mass spectrometry (GC–MS) has become increasingly popular because of its capability of identifying and quantitating a wide range of compounds (Rabaud

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Table 1
Summary of field sampling campaign.

Animal	Operation type (acronym)[a]	Location (state)	# of buildings[b]	# of visits
Swine	Gestation (GE)	Illinois	3	9
	Farrowing (FA)	Illinois	3	9
	Weaning (WE)	Illinois	3	8[c]
	Finishing (FI)	Illinois	3	15[d]
Poultry	Manure-belt layer hen (ML)	Illinois and Indiana	3	11[d]
	Tom turkey (TT)	Illinois	3	9
	Cage-free layer hen (CL)	Indiana	1	1
	Broiler (BR)	Kentucky	1	1
Total			20	63

[a] The same acronyms apply to Tables 2–10.
[b] Buildings of the same operation type are located on different farms.
[c] A summer visit was canceled because the farm closed down.
[d] Extra samples were collected from additional visits.

et al., 2003; Wright et al., 2005; Cai et al., 2006). With GC–MS, over 300 odorants have been detected in the air of CAFOs (Schiffman et al., 2001; Lo et al., 2008; Ni et al., 2012), including NH_3, H_2S, aldehydes, ketones, alcohols, acids, aromatics, amides, amines, ethers, esters, alkenes, alkenes, phenols, nitrogen-containing compounds, and sulfur-containing compounds. Many of them have relatively high boiling points and, thus, may exist in their condensed forms, i.e., in the form of particles.

The role of particles in odor transport has been an intriguing topic for many years. Day et al. (1965) claimed that in swine buildings the majority of odors were carried by particles. Hammond et al. (1979, 1981) observed that the removal of particles in swine buildings by filtration resulted in a significant decrease in odor intensity. Burnett (1969) reported a strong correlation between odor intensity and particle concentration in poultry buildings. However, a later study by Williams (1989) found that the filtration of particles in broiler buildings did not significantly reduce the odor intensity. Despite of such inconsistency in the literature, numerous odorants have been identified on particles taken from CAFOs (Hammond et al., 1979, 1981; Hartung, 1985; Wang et al., 1998; Oehrl et al., 2001; Das et al., 2004; Razote et al., 2004; Cai et al., 2006). Compared to gaseous odors, particle-borne odors are unique because particles can adhere and accumulate on the surface of objects on or near animal farms, thereby causing a persistent odor nuisance. Meanwhile, the mitigation of particle-borne odors may require different technologies and management practices.

Although efforts have been made to study particle-born odors in and/or released from CAFOs (Hammond et al., 1979, 1981; Hartung, 1985; Wang et al., 1998; Liao et al., 2001; Oehrl et al., 2001; Das et al., 2004; Razote et al., 2004; Cai et al., 2006; Lee and Zhang, 2008), little is known regarding the variability in particle odorant composition with animal operation type, season, and particle size. Moreover, in many early studies, the abundance of an odorant was simply characterized by its relative peak area (in percent) on a chromatogram, with no absolute concentration data provided. This lack of quantitative data forms a major difficulty in the assessment of particle-borne odors.

In this study, total suspended particle (TSP) and PM_{10} (particles with aerodynamic diameter <10 μm) samples were collected from 20 commercial CAFOs in the U.S. Midwest, with a total of 57 non-sulfur-containing odorants identified and quantitated. The objectives were to: (1) examine the variability in particle odorant composition with animal operation type, season, and particle size, and (2) determine the major odor contributors in each type of CAFOs.

2. Materials and methods

2.1. PM sampling

Twelve swine and six poultry buildings were visited (Table 1). Each building was visited three times with one in the cold (winter), one in the mild (spring and fall), and one in the hot (summer) season. For comparison, we additionally collected particle samples in a cage-free layer hen and a chicken broiler building but only in summer due to the budget constraint. All except for tom turkey buildings were mechanically ventilated.

Harvard impactors and UIUC isokinetic TSP samplers (Zhang, 2005) were used for PM_{10} and TSP collection, respectively. They were installed upstream of a ventilation fan that ran continuously throughout the sampling period (~24 h). In tom turkey buildings where no fans are available, the samplers were installed inside the building but near a downwind end door. The spacing of TSP inlets from the fan face was adjusted according to the air velocity to satisfy the requirements by isokinetic sampling, typically 0.2–0.6 m; whereas, in tom turkey buildings, a calm-air TSP sampling protocol (Zhang, 2005) was followed, with the spacing from the end door of 0.6–1.0 m. Harvard impactors were installed with spacing typically of 0.6–1.0 m from the fan face or end door. The installation heights of TSP and Harvard samplers were 1.2–1.4 m. PM_{10} and TSP samples were collected on 37 mm pre-baked glass-fiber filters (Type A/E, P/N 61652, Pall Corporation, Ann Arbor, MI) at a sampling flow rate of 1.2 m^3/h regulated with a venturi orifice (Wang and Zhang, 1999).

PM samplers were cleaned, dried, and assembled (with filters) in the laboratory, prior to field sampling. The samplers' air inlets and outlets were sealed with plastic caps and parafilm during transport. Once sampling was done, the particle-laden filter was transferred into a 50 mL glass vial with Teflon cap sealed with parafilm to minimize the loss in volatile components. Upon arrival in the laboratory, filters were stored at −70 °C until extracted. For each field trip, 10–14 filter samples were collected (including backup samples); but only one TSP and one PM_{10} were submitted for odorant analysis.

PM samplers and filters were visually inspected before and after field sampling to ensure that the samples were properly collected. The following problems were occasionally observed during this sampling campaign: insects trapped on the filter, severe particle bounce, and overloading of the Harvard impactors. When those happened, a revisit to the sampling site was conducted to re-collect PM samples.

2.2. Sample preparation and GC–MS analysis

Sources of standard compounds for positive identification and response factor determination are documented in Table S1. Isotope internal standards were synthesized according to the literature, or were purchased from the companies listed in parentheses: [$^2H_2$]-7,8-hexanal, [$^2H_2$]-7,8-octanal (Lin et al., 1999); [$^{13}C_2$]-1,2-acetic acid, [$^{13}C_2$]-1,2-butanoic acid, [$^2H_3$]-6,6,6-hexanoic acid, [$^{13}C_2$]-phenylacetic acid (Isotec, Miamisburg, OH); [$^2H_3$]-guaiacol, [$^2H_5$]-2,3,4,5,6-phenol, [$^2H_3$]-*p*-cresol (CDN, Pointe-Claire, Quebec, Canada); [$^2H_3$]-β,β,β-*o*-aminoacetophenone (Dollman et al., 1996); [$^2H_3$]-skatole (Preininger and Grosch, 1994).

Ten milliliters of anhydrous diethyl ether (Sigma-Aldrich, St. Louis, MO), 0.5 mL of odor-free water, and 2 μL of each labeled internal standard solution (~1 μg/mL methanol [Fisher Scientific, Fair Lawn, NJ]) were added into the particle sample dislodged from the filter surface.