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An Environmental Nuisance: Odor Concentrated and Transported by Dust

Robert W. Bottcher

North Carolina State University, Department of Biological and Agricultural Engineering, Box 7625, Raleigh, NC 27695-7625, USA

Correspondence to be sent to: Robert W. Bottcher, North Carolina State University, Department of Biological and Agricultural Engineering, Box 7625, Raleigh, NC 27695-7625, USA. e-mail: robert_bottcher@ncsu.edu

Abstract

Intensive swine production generates odorous emissions which flow from the buildings housing the animals. High ventilation rates bring in fresh air, remove heat and moisture and enhance pork productivity. Numerous compounds contribute to the uniquely offensive odors from swine facilities, including fatty acids, amines, aromatics and sulfur compounds. Dust particles, which originate predominantly from feces and feed, can adsorb and concentrate odorants in swine facilities. In addition, organic particles can decay and generate odorous compounds. Odorants can exist in much higher concentrations in the dust particles than in equivalent volumes of air. Thus, inhalation of odorous dust and deposition of the dust particles in the mucus overlying the olfactory mucosa are likely responsible for some odor-related complaints by swine farm neighbors. Accurate prediction of odor transport and dispersion downwind from swine farms may require models of dust dispersion and correlation between dust and odorant levels. Unfortunately, many approaches to estimating odor impact currently incorporate filtering of air to remove particulate matter before sensing by humans or electronic sensors. Accelerated progress in understanding this and other 'real world' odor control problems will require methodological innovations that allow quantification of odor in response to air streams containing vapor and particulate phases.

Introduction

Odor emissions from the production buildings of intensive livestock operations (ILOs) may pose a large problem in many areas of the country. These emissions arise, in part, from the need to ventilate the production buildings by moving in large amounts of fresh air to force out excess heat, moisture, ammonia and dust from the indoor air space. ILOs generate such large quantities of biological heat, moisture and waste products that dilution ventilation is the most economical and therefore predominant method of removing indoor air contaminants from the buildings. Ventilation rates needed for animal well-being in hot weather are large, typically 70–80 air changes/h (ACH), which is ~10-fold the rate typical for most other types of buildings.

Although ventilation of livestock and poultry buildings improves animal productivity and well-being, the emission of odorants in the vapor or particulate from the buildings contributes significantly to odor problems. Schiffman *et al.* found that neighbors of swine farms suffered more mood disturbances and negative emotions than a control population of rural residents (Schiffman *et al.*, 1995). The present paper reviews factors affecting the emission of swine building odorants, interactions of odorants with dust and implications for measurement of swine odors. The desired outcome is to stimulate smell researchers to develop odor measurement methods and exposure studies to more accurately account for particulate phase odorants.

Attempts to measure swine building odors

Several methods have been applied to the measurement of livestock odors, the most popular being olfactometry and scentometry. Olfactometry involves human panelists sniffing clean air and odorous air at various well-controlled dilution ratios. The scentometer is a device which allows a human sniffer to inhale air into the nose through a chamber containing odorous air that is mixed with air cleaned by a charcoal filter (Huey *et al.*, 1960). The size of the aperture allowing odorous air entry determines the dilution ratio. Researchers in Texas developed and evaluated dynamic olfactometers for ambient odor measurements and were able to compare olfactometer and scentometer measurements (Sorel *et al.*, 1983; Sweeten *et al.*, 1983). More recently, olfactometry has been applied to the measurement of swine odors at Iowa State University (Bundy *et al.*, 1993), the University of Minnesota (Clanton *et al.*, 1999) and Duke University (Schiffman and Williams, 1999).

Although quantifying odors and air pollutant concentrations are important in judging air quality, the emission rate of the pollutants is also significant in determining potential impacts downwind. The emission rate of an air pollutant from a building is the product of the air pollutant concentration in the exhaust air multiplied by the airflow rate. For example, the emission rate of dust from pigs measured in a European study involving the UK, Netherlands, Denmark and Germany averaged 0.031 mg/s/pig at an average pig weight of 73 kg (Takai *et al.*, 1998). This rate is equivalent to 2.7 kg/day/1000 head; since many typical swine buildings house ~1000 pigs, this also represents the dust emission rate per such building. The same types of emission rate calculations can be made for other air pollutants, such as ammonia and other odorous compounds, and is also being made for odors using measures of odor strength.

Since swine odors tend to be offensive to humans, the unpleasantness of the odor is an important parameter. However, the prevailing approach to quantifying swine odor strength has involved determining when panelists can barely detect the odor. This is the detection threshold or dilution ratio, which is measured in odor units (OU) (Chen *et al.*, 1999). The concentration of odor at the detection limit has been defined to be 1.0 OU/m^3 (Sneath and Clarkson, 2000), so that odor emissions can be expressed in odor units per second (OU/s) or odor units per second per animal unit (AU), where 1 AU = 500 kg animal weight (OU/s/AU). For example, Heber and Ni estimated odor emissions from swine finishing buildings to range from 5 to 36 OU/s/AU (Heber and Ni, 1999). Although this approach is contentious, i.e. many people have objected to the notion of 'odor units per cubic meter' as being physically meaningless, the measurement remains useful in some circumstances.

Although using odor units to quantify odor emissions has become popular with agricultural odor researchers, the same researchers have indicated considerable variation between laboratories in odor measurements and the methods used to quantify odor perception. This may reflect variations in the detection abilities of people as 'odor sensing instruments', for which little information is apparent in the literature. This problem is compounded by a marked lack of consensus in the operationalization and explicit definition of odor threshold. These issues may explain why researchers attempting to correlate odor measurements for swine building air samples using olfactometry with objective methods have not been very successful. For example, Gralapp *et al.* were able to correlate electronic nose and GC measurements for swine building air samples fairly well ($r^2 > 0.8$), but not electronic nose and olfactometry ($r^2 < 0.1$) or GC and olfactometry ($r^2 < 0.2$) (Gralapp *et al.*, 2000). Researchers in the chemical senses are in the best possible position to help address these deficiencies.

Complexities of the stimulus

Swine odors are typically caused by a remarkably complex mixture of odorants which can occur in the gaseous, liquid or solid (e.g. dust) phase. More than 150 compounds have been identified as contributing to swine manure odors (Eaton, 1996). Relevant odorants include alcohols, aldehydes, amines, ammonia, carbonyls, esters, indoles, mercaptans, organic acids, phenols and sulfides (Miner *et al.*, 1975; Barth *et al.*, 1984). Of these compounds, several researchers have identified low molecular weight volatile fatty acids, phenol, *p*-cresol, mercaptans, indole and skatole as contributing more to the odors (Schaefer, 1977; Spoelstra, 1980; Williams, 1984). Due to the number of compounds involved, removal of one or more individual compounds may not improve the odor quality. Additional complicating factors affecting swine building odor measurements are humidity, dust and variations in the movement of air pollutant plumes by wind.

Many people have observed dramatic increases in odor intensity and offensiveness from ILOs after rainfall or when humidity increases. Classen *et al.* correlated odor intensity of samples collected at the inlet to an experimental biofilter with ambient humidity and obtained a correlation coefficient of 0.91, with odor intensity increasing with humidity (Classen *et al.*, 2000). This effect may be due to humidity altering the distribution of odorants into the vapor versus particulate phase, the rates of enzymatic reactions producing odorants, the adsorption of odorants onto dust particles and even the delivery of odorants to the human nasal mucosa. Hence, measurements of odor concentration and emission rates using odor units are presumably greatly influenced by ambient humidity, when in fact the total odorant emission rates may not be as sensitive to humidity. When air quality regulators measure odors downwind of swine farms in response to complaints or to determine a need for an odor control program their conclusions may be dramatically affected by ambient humidity. A conclusion that odors are not problematical based on measurements taken on a dry day may therefore be inaccurate.

Another major source of inaccuracy in odor measurement is dust. Dust in intensive animal housing is primarily composed of feed components and dried fecal material, but can also contain dander (hair and skin cells), molds, pollen, grains, mites, insect parts, mineral ash and, with floor-reared poultry, litter and feathers (Carpenter, 1986; Donham *et al.*, 1986; Heber *et al.*, 1988). Several researchers have established a strong link between dust and odors (Barth *et al.*, 1984). Fecal particles can emit odors and organic dust particles can adsorb odorous compounds, including ammonia. Hammond *et al.* extracted odorous compounds, including acids, phenols and carbonyls, from dust collected from air in a swine building and concluded that the concentrations of some odorants, such as *p*-cresol and butyric acid, are of the order of 10^7 times greater in aerosols than equal volumes of air (Hammond *et al.*, 1981). Although the data indicated that there may be five times more odorant molecules in the gas phase than are adsorbed on aerosols, removal of the aerosols reduced odors, leading Hammond *et al.* to suggest that aerosol particles amplify odors by concentrating odorous compounds and by deposition on the olfactory mucosa (Hammond *et al.*, 1981). Hartung reviewed the relevant literature and noted that at least 60 compounds from different groupings were identified in dust from animal houses (Hartung, 1986). Volatile fatty acids and indolic/phenolic compounds contributed to the strong animal house odor, with the main components being acetic acid and *p*-cresol, respectively (Hartung, 1986).

With dynamic olfactometry (Hobbs *et al.*, 1995; Chen *et al.*, 1999; Schiffman and Williams, 1999) air samples are presented to trained odor panelists over a series of dilution ratios. This method provides the detection threshold that may be used to characterize odor concentration in OU/m^3. Unfortunately, the method typically involves filtering dust from the air samples before dilution and delivery to the panelists to avoid fouling of the apparatus by dust. A recent European standard for dynamic olfactometry specifically excludes odors from particulates (Sneath and Clarkson, 2000). Hence, the portion of odor responses due to dust-borne odorants is presumably not accurately represented. Regulators measuring odors using methods which filter dust particles may underestimate the problem facing a farm neighbor and effective dust control methods may be unfairly judged to be ineffective at odor control.

Another potential source of error is plume movement and dispersion by wind; as plumes of polluted air travel from a swine farm, their movement and dispersion are affected by wind shear (wind velocity profile), local circulations due to irregular terrain, turbulence in the wind and stability of the atmosphere (a tendency to resist vertical mixing, often greatest in the early morning) (ASME, 1979). Regulators should therefore not be expected to arrive at a site during atmospheric conditions identical to those associated with nuisance odor levels, but making measurements during stable atmospheric conditions with the wind approaching from a suspected odor source should help address errors due to plume behavior.

Opportunities to improve measurements

Despite the problems affecting measurement of odor parameters and emissions, some promising approaches have been developed. Scentometry allows measurement on site, which can eliminate errors due to changes in air samples occurring during transport to odor laboratories and also does not filter out dust.

Another approach which can directly incorporate dust effects involves static headspace sampling, where air in contact with an odorous liquid or solid in a vessel is sniffed by humans. Marin compared detection thresholds from humans sniffing the static headspace above eight different odorous liquids with gas chromatography olfactometry (GCO), which involves humans sniffing odorants as they are analyzed by the gas chromatograph (Marin, 1999). This work found no statistical difference in threshold values between the two measurement methods for most compounds. This result may be helpful in that some methods of preparing odorant samples for headspace sampling can incorporate dust.

Cloth swatches which had been placed in air streams or odorous environments for specified periods of time have been used in a headspace application by inserting exposed swatches into glass containers for later sniffing by trained panelists (Miner and Licht, 1980; Schiffman and Williams, 1999). Aspirating the swatches by pulling airflow through them for differing durations allows adjustment of the odor intensity of the swatches (Miner and Licht, 1980). Since this method impregnates dust particles in the swatches, it may facilitate measurement of odors having a significant dust-borne component. Zhang *et al.* correlated odor intensity of aspirated cloth swatches with the amount of odorous air passed through the swatches and observed a need for moist air conditions to avoid rapid odor losses (Zhang *et al.*, 1999). Although cloth swatches can apparently incorporate dust-borne odorants, the fabric can adsorb volatile odorants as well as dust particles. Accurate measurement of both the vaporous and particulate odors may therefore require more sophisticated techniques.

Development of standardized odor sources may also facilitate calibration of odor measurement methods and quantification of errors. For vaporous odorants synthetic mixtures designed to simulate the odor of swine manure have been developed for use in odor research. Kim-Yang *et al.* specified a mixture of 11 odorants which produces realistic swine odors (Kim-Yang *et al.*, 1999). Such mixtures are useful for calibrating gas chromatographs and odor panels and may be applicable to human exposure studies. A synthetic swine dust was produced by Wathes *et al.* from swine feces, feed, and straw which was dried and milled (Wathes *et al.*, 1999); the dust is remarkably odorous and realistic. Like the synthetic manure slurry for producing vaporous odorants, such an artificial dust has potential applications for calibrating measurement methods and conducting human exposure studies. It can also be used in training workshops to emphasize the odorous nature of the dust.

Needs for chemoreception research

The production and transport of odorants from swine farming operations have a significant impact on the well-being of farm neighbors and the viability of swine operations. Improved methods of quantifying odorants in the particulate and vapor phases and apportioning the relative strength of odors from particulates and vapors will be needed before the effectiveness of dust control approaches can be accurately measured. Modifications of olfactometry and aspirated fabric swatch techniques may enable such apportioning. As concern about physical health effects of air pollutants from swine farms intensifies, correlations between particulate phase odorants and respiratory effects of the particulates would be helpful in characterizing the importance of dust control. Exposure studies to determine short-term physiological effects of low levels of swine farm vapors and dust on humans would assist in developing such correlations.

Conducting such studies in environmental exposure chambers is problematical due to the need to avoid contamination of air distribution equipment by odorous dust and difficulties in generating representative mixtures of odorants from manure or synthetic odorants. However, the recent development of standardized synthetic odorant mixtures and artificial pig dust may facilitate such laboratory studies. Conducting exposure studies on or near swine farms is also problematical due to the tendency of humans to be desensitized by swine farm odors on the farm and the need to provide control (clean air) exposures while in an inherently polluted environment. The same factors responsible for intense odor sensations from exposure to dusty air in the field, i.e. the concentration of odorants on particles and difficulty in cleaning air and surfaces contaminated with such dust, makes it difficult to quantify cognitive responses to dusty air samples in laboratory settings. Chemoreception scientists are well placed to facilitate development and evaluation of odor control technologies by addressing these concerns.

Conclusions

Dust particles in swine buildings may be responsible for a considerable portion of odorant emissions from the buildings and odor perceptions by downwind neighbors of swine farms. A reduction in organic dust levels in swine building airflows has been associated with odor reduction. Methods of measuring swine odors from air samples which include dust generally require filtering of the dust to avoid instrument problems, so methods to adequately account for dust-borne odors are needed. In many cases odor control will require a reduction in dust emissions from buildings. Chemoreception scientists can help address these issues by developing improved odor measurement techniques which better account for particulate phase odorants and apportion vaporous and particulate odors and odorants and by conducting exposure studies which quantify human physiological responses to low levels of odorous dust and vapors representative of conditions downwind from swine farms.

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