A Review of Literature Concerning Odors, Ammonia, and Dust from Broiler Production Facilities: 1. Odor Concentrations and Emissions

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Primary Audience: Extension Specialists, Poultry Scientists, Poultry Farm Managers

SUMMARY

Odors from broiler production facilities are the consequence of odorant molecules produced by microbial activity in the litter. The impact of odor on the public can be evaluated by the frequency, intensity, duration, and offensiveness of the odors. Currently, much of the work reported in the scientific literature is directed toward measurement of odor intensity by determination of the odor concentration through threshold olfactometry. Several researchers have reported values for odor concentration in or near broiler production facilities, ranging from 80 to 2,000 odor units, and some researchers have reported odor emission rates. This paper briefly reviews measurement methods for odor concentration and intensity, summarizes the values reported in the literature for odor concentration for broiler houses, discusses the relationship between odor concentration measurements and odor intensity, and reviews the literature to determine if a correlation between odor concentration and ammonia and dust emissions exists.

Key words: broiler production, odor, ammonia, particulate matter, litter management

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DESCRIPTION OF PROBLEM

Odors are indigenous to all livestock production operations. In modern production facilities, odors are generated primarily from the confinement buildings, from manure storage structures, from manure or storage effluent applied to cropland, and from disposal of dead animals. Odor is defined by human olfactory perception of a mixture of chemical compounds in the atmosphere also known as odorants. There has been a limited amount of information directly related to odor production and emissions from poultry operations, although there has been significant research on other species, especially swine production. The objective of this paper is to review the current literature related to the emissions of odors and related pollutants from broiler housing and to draw inferences from literature of other species for broilers where appropriate.

Broilers are generally raised in enclosed buildings on beds of absorbent material (i.e., litter), typically an agricultural by-product, such as wood shavings or rice hulls. While some

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odors may be emitted from the birds directly, the majority of odorants, including ammonia, are the natural by-products of microbial degradation of uric acid and feces. The conversion of nitrogen in the feces to ammonia has been shown to be a function of temperature, litter moisture, litter pH, and ventilation rate [1, 2], and odors have been shown to increase in offensiveness with the moisture content of the litter [3]. An Australian study showed that ammonia and odor concentrations within a broiler building reached a plateau when the total bird weight reached a maximum, typically at 6 wk. Odor concentrations varied with ventilation rates, litter moisture level, and building design. Gas composition analysis inside the broiler building confirmed that ammonia and dimethyl disulfide were, by volume, the major odorous constituents [4].

Although the US Environmental Protection Agency does not have specific federal standards or rules for odor, odor is regulated as a nuisance. A nuisance is generally defined as interference with the normal use and enjoyment of property. A number of ways have been used to quantify odors to determine if a nuisance condition exists. One system employs the FIDO principle, which represents 4 basic characteristics: Frequency, the number of times the odor is detected in a given time period; Intensity, the strength or concentration of an odor; Duration, the length of time that an odor remains detectable; and Offensiveness, the character or hedonic tone of an odor [5]. Most states address odors in their regulations either directly or indirectly. Direct regulation is a specific rule or odor standard that prohibits the emission of an odor over some limit. Because of the difficulties in quantifying odor, most odor regulations attempt indirect methods of odor control. The goal of indirect methods is to minimize or reduce odor problems without specifically regulating odor emissions. The most common indirect methods include setbacks, permitting, operator training, and land application restrictions. As of 2000, there were only 6 states that did not have some form of odor regulation for concentrated animal feeding operations. Ten states had rules or regulations directly limiting odor emission from concentrated animal feeding operations, and 34 other states had some form of indirect limitation [6].

ODORS AND ODOR MEASUREMENTS

The 4 principle classes of odorants are (1) branched and straight-chain volatile fatty acids (VFA), (2) ammonia and volatile amines, (3) indoles and phenols, and (4) volatile sulfur containing compounds. The VFA are an intermediate product in the anaerobic fermentation of biological wastes to methane (CH_4). When conditions are such that an incomplete fermentation occurs, then VFA can be volatilized to the atmosphere. Ammonia and volatile amines are the product of deamination and decarboxylation of amino acids. Deamination results in the production of VFA, carbon dioxide (CO_2), hydrogen gas (H_2), and ammonia (NH_3) under neutral pH (6 to 7). Microbial breakdown of uric acid in broiler litter is another major source of ammonia. Indoles and phenols are the by-products of amino acids metabolized by a variety of intestinal anaerobes. Volatile sulfur compounds are the by-product of anaerobic digestion of sulfates and sulfur-containing amino acids [7].

A number of empirical studies to determine the concentration and emission of NH_3 from broiler operations have been conducted [4, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19]. Much of the interest in ammonia has been driven by concerns for animal welfare [20], worker safety [21, 22], or environmental impact [23]. A laboratory study of poultry odorants [24] identified a number of other odorous compounds in the waste or in the air from poultry buildings. These compounds included organic acids (acetic, butanoic, and pentanoic), sulfides (dimethyl-disulfide and dimethyl-trisulfide), and nitrogen compounds (indole, 3-methylindole, and 2-methyl-1H-purine) as well as phenol, cresol, 2-furanmethanol, and 2-methyl-2-butenale. A review paper by O'Neill and Phillips [25] listed a number of odorous compounds associated with poultry production.

Sensory measurement of odors is a complex science with a variety of available techniques [5, 26]. The situation is further complicated because of the presence of up to several hundred odorants for a particular livestock or poultry operation [25]. Of the various ways to classify odors, concentration and intensity are of particular interest since they can be quantified by sensory methods. Odor concentration is generally measured in either a laboratory setting or in the field using threshold olfactometry. The most commonly used laboratory method for odor concentration is dynamic forced choice olfactometry in which the number of dilutions with odorless air required for an odor to be detected by 50% of a panel of observers is the measure of concentration [27]. This is an objective measurement; however, it does not provide an exact measurement. Differences between odor panelists, sample handling, equipment, and calculation procedures contribute to variability [26, 28, 29]. Over the last 20 yr, there have been efforts to standardize the methodology used in dynamic forced choice olfactometry with the method described in the European Standard [30, 31] currently being used by most olfactometry laboratories both in Europe and in the US and Australia. However, laboratories compliant with the European Committee of Standards (Committe' Europěen de Normalisation) still exhibited a CV of 32%, and those "compliant in essence" had a CV of 55%. Laboratories not compliant with the European Committee of Standards exhibited a CV of 104% [32].

Field measurements are generally done using a static olfactometry method with an instrument known as a field olfactometer or scentometer [33, 34, 35]. Currently, there are 2 commercially available instruments: the Barneby Sutcliffe Scentometer [36] and the St. Croix Sensory Nasal Ranger Field Olfactometer [37]. Both instruments use a series of graduated orifices that are set to certain detection threshold (DT) values. The person taking the measurement places the instrument on his/her face and nose and allows activated carbon filtered air to enter. Then, the smallest orifice is then uncovered to determine if an odor is detected. If no odor is detected, this orifice is covered and the second smallest is uncovered. This process continues until an odor is detected. Once an odor is detected, the orifice that is uncovered defines the DT value by the relative areas of the inlet of filtered odor-free air and the inlet of odorous air. Field olfactometers have a limited number of DT values available; for example, the Barneby Sutcliffe Scentometer allows for measurements at DT values of 2, 7, 15, 31, 170, and 350 in which a value of 2 represents the weakest odor and a value of 350 represents the strongest odor. Field olfactometers have several advantages over laboratory methods: lower detection limits, immediate results, no deterioration of odor during transit, and low per sample cost [34]. However, this method also has disadvantages versus laboratory methods, including a limited number of samples and participants, absence of a controlled environment for testing, inability to shield the participants from ambient odors with possible olfactory fatigue as a result, restriction of the panelist indicator to a yes or no response, difficulty in providing odor-free air, and potential for bias based on other sensory input. However, despite the shortcomings, field olfactometry is currently being used by several states for regulatory measurement [6].

For either laboratory or field methods, odor concentrations are reported in units of DT. It has been customary in the literature to equate odor units (OU) or the threshold odor number to DT values with these expressions being used interchangeably. Thus, the concentration at the detection threshold is defined as 1 OU [38]. The European Standard [31] defines one odor unit (OU_E) as equivalent to the response elicited by one European reference odor mass, most commonly 123 μg n-butanol evaporated into 1 m^3 of neutral gas, with a resulting definition of the reference concentration as one OU_E m^{-3}. The choice of units in the European Standard, while convenient for calculations [39, 40], is not consistent with the physical measurement. For any odor comprised of more than 1 pure chemical species (e.g., odors encountered at poultry operations) the OU is a relative concentration, the ratio of 2 volumes, and there is no physical basis for dividing OU by volume [38, 41]. It implies that an OU is equivalent to a unit of mass, which it is not, but rather a combination of each mass of the odorants. A continuity equation (e.g., mass balance) cannot be written for odor as a single entity, although equations can be written for each of the odorants in the mixture. Changes in the mixture of odorants, chemical reactions of odorants, and changes of state (e.g., gas to liquid or gas to solid) may alter the threshold concentration of the odor. Treating the odor as a single "mass" ignores these potential changes and should be viewed with caution.

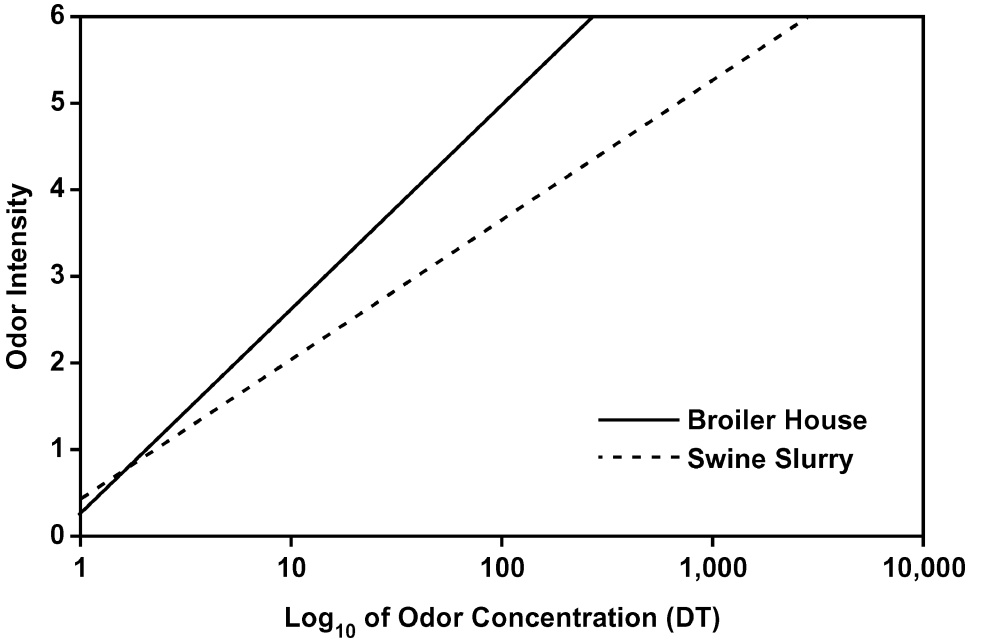

FIGURE 1. Odor intensity vs. odor concentration for air exhausted from a broiler house and field applied swine manure slurry, based on equations given by Misslebrook et al. [45].

Odor intensity is generally measured through 1 of 2 methods. A subjective measure of odor intensity compares the perceived strength of an odor to the subject's internal reference. The intensity is ranked against an ordinal scale employing from 3 to 10 categories [5]. A typical 6-point intensity scale is as follows: 0 = no odor, 1 = very faint odor, 2 = faint odor, 3 = distinct odor, 4 = strong odor, and 5 = very strong odor.

The subjective nature of this method creates some difficulty in comparing data between laboratories and in some instances within a given laboratory. The differences between values may not be equal (i.e., an odor intensity score of 4 may not necessarily be twice as odorous as an intensity score of 2). Likewise, differences in sensitivity between individuals may be greater than one value for a given odor. However, the subjective method is frequently used as it is inexpensive, rapid, and does give some indication of odor intensity.

An objective method of determining the odor intensity utilizes suprathreshold olfactometry [42]. This method matches the perceived intensity of a sample odor against the intensity of a known dilution of a known odorant, typically n-butanol. This method can either be applied in the laboratory [43] or in the field [44]. An objective determination of odor intensity has an advantage over an odor concentration measurement for many instances of ambient odor assessment. Many of the odorants typical of poultry environments have low odor threshold values, i.e., they are detectable in concentrations of parts per billion, which means that they have a high intensity at a low concentration.

The relationship between odor concentration and odor intensity is important to establishing the effect of the odor on the public and in determining effective abatement strategies. Odors are controlled by reducing the amount of odorants in a given volume of air (concentration), but the reduction in the nuisance quality of the odor is related to the strength of the odor (intensity). Misselbrook et al. [45] compared odor intensity based on a 7-point scale vs. odor concentration as determined by threshold olfactometry (DT) for emissions from a broiler house and from field applied swine slurry. A graph of the relationship between odor intensity and odor concentration based on their equations is shown in Figure 1. The odor intensity starts at the detection threshold of 1 and increases with the log of odor concentration until the maximum intensity

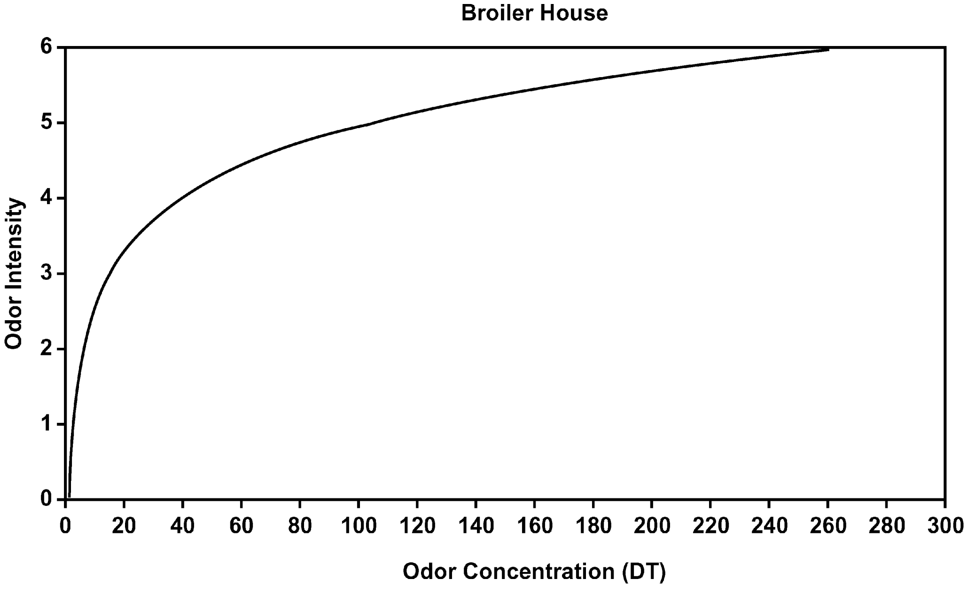

FIGURE 2. Odor intensity vs. odor concentration by threshold olfactometry for air exhausted from a broiler house, based on an equation given by Misslebrook et al. [45].

rating of 6 is reached. The broiler house odor had a much steeper relationship and reached the maximum intensity value of 6 at an odor concentration of around 260 DT, while the swine slurry reached an odor concentration of almost 3,000 before exceeding the intensity scale. An equal increase in odor concentrations for broilers vs. swine would result in a greater increase in odor intensity and a greater nuisance effect for the broilers. Conversely, an equal reduction in odor concentration for broilers vs. swine slurry would result in a larger decrease in odor intensity and nuisance for the broilers.

The other important aspect to this relationship is that as the odor concentration continues to increase, the magnitude of increase in the intensity response gets smaller. This is easier to see when the intensity is plotted vs. the concentration instead of the $\log_{10}$ of the concentration as in Figure 2 for just the broiler house relationship. As the odor concentration becomes larger, the human olfactory system shows less and less of an increase in intensity response. This means that a reduction in odor concentration from 240 to 40 DT will have less of an impact on odor intensity then a reduction in concentration from 40 to 1 DT would produce. Odor concentrations by threshold detection are frequently used as an indicator of intensity but the above relationship must be kept in mind.

Odor concentration measurements have been the primary tool used in the literature to characterize the odor strength. However, the nonlinear relationship between concentration and intensity would suggest that odor intensity measurements, particularly by an objective method, such as suprathreshold olfactometry, may be preferred to determine the effect of odors on the public. In a review of odor measurement methodology, Leonardos [46] discussed the shortcomings of relying only on threshold dilution measurements and suggested a process in which 4 environmental odor attributes, character, hedonic tone, threshold, and intensity, could be quantified. In contrast with the FIDO assessment of odor nuisance, these attributes quantify odor strength through concentration and intensity measurements and offensiveness by hedonic tone and character.

ODOR MEASUREMENTS FOR BROILER PRODUCTION

Several European and Australian studies regarding odor concentrations measured within or adjacent to broiler houses have been reported [4, 8, 18, 45, 47, 48]. These data are summarized in Table 1 as reported by the authors. Robertson

TABLE 1. Literature values for odor concentrations in broiler houses for birds on litter

Reference	Odor concentration	Analysis method	Notes
Williams [48]	84–586 detection threshold (DT) values	Dynamic dilution olfactometry, no standard method referenced	Range of measurements over 2 wk for raw air
Misslebrook et al. [45]	1,000 odor unit (OU) m^{-3}	Dutch prestandard on olfactometry (1990)	Value is reported as "typical" for broiler houses
Amon et al. [8]	500–2,080 OU m^{-3}	Dutch prestandard NVN 2,820	
Jiang and Sands [47]	120–1,500 OU m^{-3}	Dutch prestandard NVN 2,820	
Jiang and Sands [4]	50–1,000 OU m^{-3}	Dutch prestandard NVN 2,820	
Robertson et al. [18]	600–800 OU_E m^{-3}	European draft protocol prEN 13,725	16-d-old birds
	1,300–2,300 OU_E m^{-3}		30-d-old birds

et al. [18] noted that methodological differences between the Dutch National Standard (Netherlands Normalization Institute, NVN2820) and the predstandard European Committee of Standards protocol (Committee European de Normalisation, prEN13725) required that values obtained using NVN2820 be divided by "approximately 2" to compare with the values taken using prEN13725. Many of the odor concentration values in Table 1 exceed the upper bound for the odor intensity measurements reported by Misselbrook et al. [45].

Odor emission rates for broilers have also been reported. Amon et al. [8] reported odor emissions ranging from 200 to 3,200 OU/s (approximately 0.01 to 0.2 OU_E/s per bird) for 2 commercial broiler buildings with about 8,000 birds each in Slovenia. Ogink and Groot Koerkamp [49] studied 2 commercial broiler operations in The Netherlands and reported odor emission rates from 0.06 to 0.41 OU_E/s per bird. Robertson et al. [18] reported odor emissions of 20,000 to 33,000 OU_E/s (approximately 0.6 to 0.97 OU_E/s per bird) for 4 commercial facilities with about 34,000 birds each in the United Kingdom. Hayes et al. [50] reported mean odor emission rates for 3 commercial operations in Ireland of 0.39, 0.58, and 0.66 OU_E/s per bird. However, these values should be viewed with caution. They were arrived at by multiplication of odor concentration expressed in units of OU m^{-3} by the ventilation rate (m^3 /s) and in some cases dividing by the number of birds to arrive at an odor emission rate. Differences between a number of extraneous parameters, including location, climate, ration, flock management, and litter handling, could result in significant differences in odor intensity for similar values of odor concentration. Additionally, it seems reasonable that a change in ventilation rate would alter the measured odor concentration in the building by dilution so that only odor concentration measurements that correspond to each ventilation stage be multiplied by that stage to reach an emission rate. Measurement of ventilation rate, particularly in naturally ventilated buildings, is challenging, and the uncertainty of these measurements may exceed ±20% [51].

CORRELATION OF ODORS WITH AMMONIA OR DUST

Because of the difficulty in measuring odors under field conditions, researchers have attempted to correlate odor intensity or concentration to the concentration of specific gases [52]. For poultry, NH_3 is the odorous gas produced in the greatest amount, although NH_3 has a relatively high odor threshold value of 0.3 to 53 ppm [53]. In a trial of a zeolite litter treatment, Amon et al. [8] demonstrated a significant correlation between ammonia concentration and odor concentration. However, in a second trial of a different litter treatment, they were unable to confirm the correlation. Ogink and Groot Koerkamp [49] attempted to correlated odor and NH_3 in 2 trials with broilers but were not able to obtain a significant correlation coefficient. Guo et al. [54] were also unable to correlate NH_3 with the threshold odor concentration for poultry buildings. For other livestock, hydrogen sulfide (H_2S) has been used as an odorous trace gas as well as a regulated pollutant in some states [6]. Studies of commercial broiler operations in Canada did not detect H_2S at levels above the minimum detection threshold for the instrument of 10 parts per billion [16].

A number of odorants have been shown to be carried by dust particles in swine facilities [55, 56, 57, 58, 59]. These studies used laboratory techniques to extract odorants from dust particles sampled from swine buildings. The authors hypothesized that a reduction in odor would occur with a reduction in the dust concentration in the air. However, in a study that considered dust-borne odors in a commercial broiler house, the odor concentration of the air was measured with and without dust removal by electrostatic precipitation [48]. No significant difference was seen in odor concentration despite a significant amount of dust removal nor was any significant correlation reported between dust concentration and odor concentration. The author did report a subjective increase in odor intensity when the dust particles were filtered, suggesting that the presence of the dust in some way mitigated the impact of the odor. The contrast between these studies is indicative of the difficulties faced in measurement and control of odor in livestock and poultry environments. It is likely that there are a significant number of odorants attached to dust particles, but there may still be enough odorants in the air to maintain the threshold odor concentration regardless of dust removal.

CONCLUSIONS AND APPLICATIONS

1. Odors are the result of the generation of odorants from microbial degradation of a variety of chemical compounds in the litter.
2. Odor concentration as measured by threshold olfactometry has been the primary method to quantify odors in poultry operations, although intensity, character, and hedonic tone are equally important criteria for public perception as well as frequency and duration of the odor.
3. There is a nonlinear relationship between odor concentration and odor intensity, which compounds the difficulty in drawing conclusions about the effect of the odor on the public. Because of the challenges and costs for sensory measurements, there have been some efforts to relate odor concentration to ammonia concentration or dust concentration but these have not been successful for broilers.
4. Odor from broiler operations is an ongoing and significant concern for the industry; however, efforts to date to quantify the odor problem leave a number of questions unanswered and are open to challenge if applied in a regulatory process.

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