Downwind Air Quality Measurements From Poultry and Livestock Facilities

Wendy Powers, Associate Professor of Animal Science,
Sarah Bastyr, Assistant Scientist

A.S. Leaflet R1927

Summary and Implications

Air samples were collected at and downwind from poultry, dairy and swine facilities during two summer sampling periods. Samples were analyzed, onsite, by an electronic nose and a Jerome meter for H_2S concentration. Collected air samples were analyzed using olfactometry and gas chromatography. Data were analyzed to determine specie and site differences for gaseous concentrations and odor. From collected data, equations for downwind concentrations for gaseous compounds and odor were developed. Prediction equations for odor were developed from analytes quantified by gas chromatography. Correlations between olfactometry measures and both electronic nose and gaseous concentrations were determined. H_2S was best correlated to odor. Climatic conditions influenced odor, H_2S and gaseous compound concentrations.

Management practices are an important factor in determining emissions from animal feeding operations; perhaps of equal or greater importance than the specie itself. Identification of specific compounds that likely contribute to malodor and, in particular, relate to observed differences in odors emanating from production facilities of different species, can be used in conjunction with specie-specific siting tools. Concentrations of particulates and gases generated from this study will be used to further develop such tools.

Introduction

Attention to gaseous emissions from poultry and livestock facilities continues to be a prevalent issue for the industry. Limited work has been conducted that thoroughly characterizes the composition of air collected at or near animal production facilities (Zahn et al., 1997; Gralapp et al., 2001). Even more restricted is work that goes on to quantify a substantial number of identified compounds from these samples at multiple locations within and beyond the facility borders. Blind studies have demonstrated that there are differences in odors associated with poultry, dairy and swine (Powers, unpublished). Over 100 compounds have been identified in air samples collected from animal production facilities (Miner, 1995). Thorough investigation of the compounds that result in these differences will provide a better understanding of the compounds that must be controlled to avoid nuisance conditions. Electronic nose technology has proven to be a useful tool in the food and beverage industry for quality control measures (Persuad, 1992). However, little work has been published to assess the potential of the electronic nose as a means of quality control for agricultural odors. Earlier research had determined that this instrument could discriminate between odors at high concentrations (Gralapp et al., 2001).

As regulatory action is discussed at state and federal levels, adequate characterization of gaseous emissions (concentrations and components) is needed. Additionally, methods to evaluate emissions, for compliance purposes, are necessary. The specific objectives of this research were to:

- Characterize gaseous concentrations in and around animal production facilities
- Elucidate the compounds (volatile organic compounds and hydrogen sulfide) that contribute to widely varying odor character among species
- Evaluate and refine electronic nose technology as an objective, portable alternative to olfactometry

Materials and Methods

Air samples were collected from Iowa poultry, dairy and swine operations twice weekly for a 10-wk period, between May and August during Year 1 (2001) and Year 2 (2002). Not all operations were initiated concurrently in order to accommodate pig flows. During Year 1, two commercial layer operations, a 1200-cow commercial dairy farm, an Iowa State University dairy with a freestall barn, a 1300-hd finishing swine operation, and a finishing barn located on an Iowa State University swine farrow-to-finish farm served as collection sites for these species. During Year 2, a third layer facility, two commercial swine breeding and gestation operations with earthen manure storage systems equipped with aerators systems and three additional deep-pit swine finishing operations were added to the sites used in Year 1 as collection sites.

During Year 1, samples were collected indoors, only. During Year 2, samples were collected from a source (0 m from a building) and from points downwind of the source (approximately 50, 100, and 200m). Actual distance from the building was recorded for each collection point. Sites that were sampled in both project years had an additional sample collection point inside of the building. Wind direction was identified and sampling points determined accordingly on each day of sampling such that all measurements were always collected downwind of the source. On each sampling day, solar cover was characterized (i.e. sunny, partly sunny, cloudy, partly

cloudy, raining) and temperature, humidity, and wind speed data were recorded at each site.

While on-site at each facility, analysis using a portable CyraNose 32-sensor electronic nose (Cyrano Sciences, Pasadena, CA) was conducted during both project years. Air samples for gas chromatography-mass spectrometry (GC-MS) analysis were collected via adsorption onto solid phase micro-extraction (SPME) fibers (Supelco, Inc.; Bellefonte, PA). Fibers were brought back to Iowa State University for analysis on a GC 6890 and MS 5973 (Agilent Technologies, Palo Alto, CA). The stock standard solution used for the GC-MS contained 32 compounds which could be identified and quantified. The six classes of compounds represented in the stock standard solution were: volatile fatty acids, phenols, indoles, alkanes, thiols and sulfides. Air samples were collected in 10-L Tedlar bags for transport to the olfactometry laboratory at Iowa State University. Human assessment of the samples was conducted using an As'cent olfactometer (St. Croix Sensory, Stillwater, MN) and eight trained panelists. These panelists determined the odor detection threshold for each sample. The odor detection threshold refers to the amount of clean air that is needed for the air sample to be detected by only 50% of the panelists. The higher the value assigned to the sample, the stronger the odor. A Jerome meter (Arizona Instruments, Inc., Tempe, AZ) was used to collect onsite measurements of hydrogen sulfide concentrations during Year 2, only. The Jerome meter has a detection range of 0.003 to 50 ppm with a relative standard deviation of 5%.

All data were analyzed by procedures of the SAS statistical package. A general linear model was used to determine the fixed effects of species, site within species and location of sampling (inside or outside of the building) on measured variables. Stepwise linear regression was used to develop an odor prediction equation from analytes quantified by GC-MS, predict the electronic nose response from GC-MS and to develop H_2S and acetic acid concentration prediction equations as well as an odor dilution threshold equation. Simple correlation procedures were used to determine the relationship between olfactometry and the electronic nose (after the 32 sensor responses from the electronic nose were reduced to one value by Principle Component Analysis).

Results and Discussion

Chemical constituents and odor threshold of sampled air

Least square means of all indoor measurements for each study site, indicate that while specie had a significant effect on some measures (hydrogen sulfide, acetic acid, propanoic acid, butyric acid, valeric acid, and 4-methylphenol) site effects were limited to hydrogen sulfide, butyric acid, and valeric acid. Large standard deviations in measures over sampling days resulted in species and site within species being insignificant ($P>0.05$) for these measures.

Least square means of all measurements taken immediately outside of the building (0m) of each study site, show that specie effects were observed for odor, acetic acid and propanoic acid concentrations. Site within specie effects were observed for propanoic acid concentrations, only.

Climatic Effects

Because, samples were always collected in a downwind direction of the building source, wind direction was not a significant term. Windspeed only affected phenol, decane, and undecane concentrations ($P<0.05$). Solar cover influenced odor, with odor dilution thresholds being greater on sunny days. H_2S and acetic acid, which represents the concentration of VOC in this study, were also influenced by solar cover with concentrations being greater on a cloudy as opposed to a sunny day.

Correlation of olfactometry and electronic nose evaluation

Electronic nose response resulted in 32 sensor values for each sample. Using Principle Component Analysis procedures of SAS, the sensor responses were reduced to a single value that was correlated to the least squares mean of odor dilution threshold for each sample. Using all of the data points ($n = 605$), the correlation observed was 0.35. By eliminating outliers from the data set observations were reduced ($n = 588$) but correlation improved only slightly ($r = 0.39$). However, the observed correlation was considerably greater than that observed in much smaller data sets.

Development of prediction equations

Using the analytes quantified by GC-MS for all sites, across species, an odor prediction equation was developed using stepwise regression procedures. The equation accounted for 45% of the variation in response observed ($R^2 = 0.45$). Simple correlations between odor measurements and individual analytes measured by GC-MS and H_2S demonstrated that H_2S was best correlated ($r = 0.28$) followed by 4-methylphenol ($r = 0.24$), phenol, 3-methylindole, and 1-decene ($r = 0.18$, each), and butyric acid and 4-ethylphenol ($r = 0.16$, each). All other analytes had correlation coefficients < 0.10. Using data collected in both project years, the developed equation was used to predict electronic nose response. The equation accounted for 54% of the variation in response observed ($R^2 = 0.54$).

Estimating downwind concentrations of chemical constituents and odor threshold

Measurements collected at distances downwind from a building location at each site were analyzed as continuous independent variables to determine degradation curves for each measurement as it diluted with distance. Based on generated coefficients, the following equation can be used to determine the H_2S concentration on a cloudy day:

H_2S, ppb = 74.5492 – 1.9156 (distance from building, m) + 0.0072 (distance from building, m)^2 - 0.0079 (temperature, °F) + 0.9277 (humidity, %) + 5.0932

To determine the H_2S concentration on a sunny day the equation remains the same but the solar coefficient (5.0932) is omitted from the calculation.

An equation was also formulated for VOC (Volatile Organic Compounds) concentration using acetic acid as an indicator of total VOCs. On a cloudy day the VOC concentration is determined as follows:

VOC, ppm = 369.2236 – 0.3276 (distance from the building, m) – 3.5521 (temperature, °F) – 0.9672 (humidity, %) + 2.2012

This equation can also be used on a sunny day to determine VOC concentration but the solar coefficient of 2.2012 is excluded from the equation.

To calculate the odor dilution threshold (ODT) in odor units (ou), which is the number of dilutions of odor free air that are needed for the air sample to be barely detectable by 50% of the human panel, downwind from a facility on a cloudy day, the following equation is used:

ODT, ou = 16.9167 – 0.6707 (distance from building, m) + 2.2445 (temperature, °F) + 2.1044 (humidity, %) – 89.9266

Under sunny conditions the solar coefficient (-89.9266) is removed from the equation to determine the odor detection threshold.

Estimates of H_2S and acetic acid concentration as well as odor dilution thresholds values were developed for a variety of scenarios (Table 1). The current equations represent average concentrations observed in this study. More data is needed to predict concentrations downwind from 0 m concentrations from any random facility.

Major findings based on sites used in this study:

- H_2S was best correlated to odor score.
- While in the building, both site and specie affected H_2S, butyric acid and valeric acid concentrations while acetic acid, propanoic acid and 4-methyphenol although significant among species were insignificant among the sites.
- Immediately outside the building (0m), odor, acetic propanoic acid concentrations were affected by species while site within species only affected propanoic acid concentrations.
- Under the same temperature and humidity conditions, sun increased odor relative to a cloudy day.
- VOCs and H_2S concentrations were greater on a cloudy day as compared to a sunny day.
- VOCs and H_2S showed a negative relationship between concentration and temperature, whereas odor demonstrated a positive relationship.
- Odor and H_2S showed a positive relationship between concentration and humidity whereas VOCs showed a negative relationship.
- The sites studied, on average, were below proposed Iowa H_2S standards when greater than 50m downwind from the source.
- Odor dilution threshold values are not comparable to scentometry or Nasal Ranger values.

Acknowledgments

This research was sponsored by the Iowa Pork Producers Association, the Midwest Poultry Consortium, and the Animal and Poultry Waste Management Center at North Carolina State University.

References

Gralapp, A.K., W.J. Powers, D.S. Bundy. 2001. Comparison of olfactometry, gas chromatography, and electronic nose technology for measurement of indoor air from swine facilities. Trans. ASAE 44(5):1283-1290.

Miner, J.R. 1995. A review of literature on the nature and control of odors from pork production facilities. Prepared for the Odor Subcommittee of the Environmental Committee of the National Pork Producers Council.

Persaud, K.C. 1992. Electronic gas and odor detectors that mimic chemoreception in animals. Trends Analyt. Chem. 11:61-67.

Zahn, J.A., J.L. Hatfield, Y.S. Do, A.A. DiSpirito, D.A. Laird, and R.L. Pfeiffer. 1997. Characterization of volatile organic emissions and wastes from a swine production facility. J. Environ. Qual. 26:1687-1696.

Table 1. Average calculated downwind H_2S and acetic acid concentrations and odor dilution threshold values for various climatic and distance scenarios for sites used in a 2-yr study.

Distance, m	Temperature, °F	Humidity, %	Solar Cover	Calculated H_2S, ppb	Calculated Acetic Acid, ppm	Calculated Odor Dilution Threshold, ou
0	75	80	Cloudy	153	28	260
50	75	80	Cloudy	75	11	260
50	75	80	Sunny	70	9	320
50	75	40	Sunny	33	48	235
100	75	80	Cloudy	35	ND[2]	197
100	45	80	Cloudy	35	101	129
100	45	40	Cloudy	ND[1]	140	45
100	45	40	Sunny	ND[1]	138	135

[1]ND – value is below the 3 ppb detection limit of a Jerome meter.
[2]ND – value is below the 1 ppm detection limit of the GC-MS.
[3]ou – odor units, representing the number of dilutions with odor free air necessary for the odor sample to be barely detected by 50% of a human panel.