RESEARCH REPORT
ENVIRONMENT

Title: Characterization of VOCs and particulates from swine finishing facilities – **NPB #03-149**

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Abstract

Emissions from animal feeding operations have been a prominent topic in Iowa for a number of years, particularly during 2002. To address the issue a study was initiated to determine 1) if phase of production influenced air composition and odor at the facility, 2) if operations of the same type and size differ in concentrations of the compounds of interest, 3) how concentrations of compounds change as they move downwind of a given site, and 4) how climatic factors influence the concentrations downwind. Air samples were collected or analyzed onsite twice weekly at each site for a 10-week period between May and August during the 2002 and 2003 project years. During 2002, samples were collected from two breeding and gestation facilities utilizing aerated earthen storage structures and from five deep-pit finishing facilities. During 2003, two nursery sites, three breeding and gestation operations (sow sites) and 8 finishing sites were studied. Sites within a given production phase (sow or finishing facility) were matched for size of operation. Samples were collected immediately outside of a building or on the berm of the manure storage structure and at points downwind of the location (approximately 50, 100, and 200 m). Air was analyzed for hydrogen sulfide and ammonia content (onsite), odor (collected samples in 10-L Tedlar bags), and composition (volatile fatty acids, phenols, indoles, alkanes in collected samples). During sampling, temperature, windspeed and direction, humidity and solar cover were recorded. The data suggest that the type of swine system had little effect on the concentrations of most of the monitored compounds as well as odor. However, the management practices of the site itself contribute to differences in analyte concentrations to a much greater extent than production phase differences (breeding and gestation versus finishing and/or nursery production). Equations to develop downwind concentrations of all measured compounds were developed. The equations take into account temperature and humidity and are based on the concentrations at the source (ie., building or berm) that were observed in this study. All equations were compound specific. Results indicate that climatic variables, while included, were not as important to predictive capability as was source concentration or distance downwind. Prediction equations for odor, hydrogen sulfide and the volatile fatty acids, a specific group of the analyzed gases, were reasonably capable of estimating downwind concentrations, accounting for as much as 64% of the response variation. From the collected data an odor prediction equation was developed based on the measured gases. Approximately 50% of the variation observed in odor could be accounted for by the developed equation. In addition, specific gases were individually correlated to odor to determine if any, individually, could serve as a surrogate for odor. While hydrogen sulfide and ammonia were the two best indicators, each only accounted for approximately 25% of the odor response.

Introduction

Attention towards gaseous emissions from poultry and livestock facilities continues to be a prevalent issue for the industry. These emissions, once considered a nuisance concern, are now scrutinized as a public health threat. Odors have been identified by those affected as a contributor to deterioration of health, causing nausea, dizziness, eye, nose, and throat irritation, shortness of breath, stress, and drowsiness (Schiffman et al., 1998). Research indicates that while some of these effects may be perceived (Knasko, 1993) many of the responses are real physiological reactions to exposure to odorants (Donham, 1996). While the physiological effect of odor may be in question, there is no doubt that odors stemming from livestock production can be a nuisance. Many state governments have sought regulatory solutions to odor concerns. Most regulations employ either a single chemical parameter for odor indication (i.e., Minnesota has a hydrogen sulfide standard) or an olfactory assessment (i.e., Colorado uses a Scentometer, a handheld instrument used for onsite observation, manufactured by Barneby and Chaney Corp.). At the federal level, ambient air quality standards will likely be revised in the near future to address particulates and ammonia, in particular, as primary (health-based) pollutants. Some states are considering health-based standards for other pollutants as well. In February 2002, the University of Iowa and Iowa State University released a report on human health impacts from CAFOs. The EPA commissioned the National Academy of Science to develop a similar report at the national level that was released in December 2002 (National Research Council, 2002). The challenge in considering the development of standards for odor and other gases is the paucity of data that exists documenting not only 'typical' concentrations in the community and at the property line, but the health effects of long- and short-term exposures of these concentrations.

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. 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.

Objectives

During project Year 1, the stated objectives were as follows:

- *Characterize particulate and gaseous concentrations in and around both sow and finishing swine production facilities, and*
- *Study the downwind movement of the emissions*

Beyond the overarching objectives stated in Year 1, in Year 2, we added the following objectives:

- *Add at least two nursery sites to the list of sites monitored in order to further evaluate and confirm phase of production influence,*
- *Increase the total number of sites to 11 as compared to 7 monitored in 2002, to increase the number of observations for statistical purposes,*
- *Include ammonia measures into the list of analytes using collected samples to enable us to address regulatory activity in the state of Iowa,*
- *Increase sampling of outdoor manure storage structures to better elucidate their contribution, relative to the building, to total concentrations observed downwind.*

Materials and Methods

In both project years, air samples were collected from operations twice weekly for a 10-wk period, between May and August. Not all operations were initiated concurrently in order to accommodate pig flows. During Year 1, two commercial breeding and gestation operations (S) with lagoon systems (L) and five commercial deep-pit finishing operations (F) served as collection sites. During Year 2, two nursery sites (N), three breeding and gestation operations (sow sites) and 8 finishing sites were studied. All sites were located in the state of Iowa.

Air samples for gas chromatography-mass spectrometry (GC-MS) analysis, using an Agilent 6890 gas chromatograph coupled to an Agilent 5973 mass spectrometer, were collected from each site visit via adsorption onto solid phase microextraction (SPME) fibers (Supelco, Inc.; Bellefonte, PA). The SPME fibers were allowed to adsorb air samples for a 10-min period. Following collection, SPME fibers were transported in a cooler back to Iowa State University for analysis. Gas chromatography allowed for quantification of specific chemical compounds identified in the collected samples. All compounds that could be quantified using the standard procedures of the laboratory are listed in Table 1. The list represents compounds routinely identified in similar samples collected over the past four years by the laboratory. In addition, the data report generated from each sample was scanned to determine if additional compounds were routinely identified in an effort to expand the number of compounds quantified. In analyzing the data, observations below the limit of detection were recorded as 0 ppm.

Table 1. Chemical compounds quantified in collected samples using gas chromatography-mass spectrometry.

Acetic acid	Decane	Carbon disulfide
Propanoic acid	Undecane	Dimethyl disulfide
*iso*butyric	Dodecane	
Butanoic	Pentane	
3-methylbutanoic	Nonane	
Pentanoic	Tridecane	Ethanethiol
	Tetradecane	Propanethiol
Phenol		Butanethiol
3-methylphenol	Indole	
4-methylphenol	2-methylindole	1-decene
2-ethylphenol	3-methylindole	Nonanal
3-ethylphenol	4-methylindole	gamma-Butyrolactone
4-ethylphenol		
2,6-*bis*(1,1-dimethylethyl)phenol		

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. Panelists determine the odor dilution threshold for each sample; a higher value indicating a stronger odor. Further description of the procedures used by that laboratory are described elsewhere (Gralapp et al., 2001). A Jerome meter was used to collect onsite measures of hydrogen sulfide concentrations. This instrument has a detection range of 0.003 – 50ppm with a relative standard deviation of 5%. During year 1, only, particulates greater than 4 micron (PM_4) were collected throughout the sampling period at two finishing sites using an air sampling pump and particulate filters (SKC, Inc.). A 20-min sampling time was used with a flow rate of 3 L/min. Change in mass of the particulate filters represents mass of particulates collected over the sampling period. During year 2, only, ammonia concentration was measured using a Draeger PacIII. However, due to the sensitivity of the monitor (>1 ppm) readings were frequently below the instrumental detection limit. In analyzing the data, observations below the limit of detection were recorded as 0 ppm.

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. At the two breeding and gestation sites, samples were collected at the lagoon berm and downwind points of the lagoon as well. 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, raining) and temperature, humidity, and wind speed data were recorded at each site.

All data were analyzed by procedures of the SAS statistical package. A general linear model was used to determine the fixed effects of production phase, site within production phase, and source (lagoon or building) on measured variables. Regression procedures were used to develop prediction equations for downwind concentrations of each analyte based on the concentration at the building or manure storage structure. Wind direction, wind speed, and solar cover served as covariates in the model. Stepwise linear regression was used to develop an odor prediction equation from analytes quantified by GC-MS.

Results

Chemical constituents, particulates, and odor concentration of sampled air

Least square means of all measurements taken immediately outside of the building monitored for each study site, pooled across project years, are depicted in tables 2 and 3. Numerical differences in table 2 that may appear to be different, reflect large variation in measurements that occurred form one sampling day to the next for any given site. Statistical differences that occurred are illustrated in table 4 where probability levels of production phase and site within production phase effects on concentrations of measured chemical constituents are presented. *Note that no odor differences were observed within phases of production or between study sites. Within the production phases, no differences in hydrogen sulfide or ammonia concentrations were observed however, site effects did occur.* Production phase effects were observed for most of the volatile fatty acids (VFAs; acetate, isobutyrate, butyrate, isovalerate, valerate) but only a few of the heavier compounds (phenol and undecane) suggesting that the VFAs are the compounds that likely contribute to discernible differences in odor character. Odor, hydrogen sulfide, and ammonia concentrations were not different based on phase of production at the sites studied. Farm site within a given production phase effects were observed for approximately half of the measured analytes, including both ammonia and hydrogen sulfide, indicating that management within a given operation contributes to differences in analyte concentrations to a much greater extent than production phase differences (breeding and gestation versus finishing or nursery) between locations (table 4).

Fewer compounds were observed in samples collected from the lagoon berms of the S sites and analyzed by GC-MS than in samples collected from the buildings of the S, N and F sites (table 2, 3 compared to table 5). The presence of fewer compounds at detectable levels may have been the result of biological processing of manure that took place in the lagoons. The lagoons did have aerators on them potentially contributed to undetectable concentrations of the analytes of interest; most of which are the result of anaerobic processes. It is notable that concentrations of some compounds were greater at the lagoon berm than at the corresponding S building (table 3 compared to table 5) and hydrogen sulfide concentrations, in particular, appear reversed between the two sites. However, the implications of this finding may be unimportant when one considers that proposed regulatory rules in Iowa consider separation distance measures, making the source of emission within a farm indiscernible. The value in knowing what sources contribute to the emissions is in developing suitable controls for the offending portions of an operation.

Table 2. Least squares means of measures collected from locations immediately outside of each study site building (0 m).

Production phase		Finish	Finish	Finish	Finish	Finish	Finish	Finish	Finish
Measure	*Site*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
Particulates	mg/L	163	316						
Odor Dilution	ou[1]	282	506	362	357	430	340	228	303
NH_3	ppm	<0.00							
		1	1.289	<0.001	.722	2.265	.134	2.013	.078
H_2S	ppm	0.133	0.233	0.008	0.090	0.188	0.082	0.103	0.121
Acetate	ppm	69.25	49.82		42.90	48.43			
		5	8	63.579	7	3	6.292	7.251	5.640

Propionate	ppm	3.863	3.484	<0.001	<0.001	0.264	0.392	0.195	0.360
Isobutyrate	ppm	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001
Butyrate	ppm	3.644	1.347	<0.001	0.507	0.292	0.138	0.165	0.210
Isovalerate	ppm	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001
Valerate	ppm	0.768	0.074	<0.001	0.006	<0.001	0.004	0.004	0.011
Phenol	ppm	0.559	0.691	0.167	0.160	0.196	<0.001	<0.001	<0.001
4-Methylphenol	ppm	0.245	0.424	<0.001	0.022	0.015	<0.001	<0.001	<0.001
4-Ethylphenol	ppm	0.002	0.021	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
3-Methylindole	ppm	<0.001	0.006	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
γ - Butyrolactone	ppm	6.909	23.030	219.461	25.734	24.520	11.919	16.776	10.349
Nonanal	ppm	15.728	1.787	<0.001	4.274	3.665	<0.001	<0.001	<0.001
Decane	ppm	2.640	0.536	1.140	0.693	1.381	<0.001	<0.001	<0.001
Undecane	ppm	4.515	1.744	7.565	2.439	2.476	0.112	0.278	0.000
Dodecane	ppm	3.055	1.713	16.014	2.763	1.816	0.444	0.716	0.323
Nonane	ppm	0.000	0.021	0.327	0.133	0.032	0.017	0.037	0.011
Tridecane	ppm	2.880	4.401	1.929	1.758	0.695	0.089	0.342	0.458
Tetradecane	ppm	6.496	1.057	0.591	1.128	0.981	0.032	0.011	0.059
1-Decene	ppm	0.000	0.048	<0.001	0.044	0.000	0.003	<0.001	<0.001

[1]ou – odor units, representing the number of dilutions with odor free air needed for the odor sample to be barely detected by 50% of a human panel

Table 3. Least squares means of measures collected from locations immediately outside of each study site building (0 m).

Production phase		Nursery	Nursery	Sow	Sow	Sow
Measure	*Site*	*A*	*B*	*A*	*B*	*C*
Odor Dilution	ou[1]	231	258	296	327	180
NH_3	ppm	1.567	2.062	0.387	0.373	1.821
H_2S	ppm	0.145	0.156	0.128	0.096	0.140
Acetate	ppm	3.892	4.334	24.817	45.810	<0.001
Propionate	ppm	<0.001	0.493	0.054	0.093	<0.001
Isobutyrate	ppm	0.002	0.002	<0.001	<0.001	<0.001
Butyrate	ppm	0.024	0.117	0.294	0.145	<0.001
Isovalerate	ppm	<0.001	0.001	<0.001	<0.001	<0.001
Valerate	ppm	0.007	0.009	0.005	<0.001	0.008
Phenol	ppm	<0.001	0.003	0.120	0.169	<0.001
4-Methylphenol	ppm	<0.001	<0.001	0.032	0.079	<0.001

4-Ethylphenol	ppm	<0.001	<0.001	0.006	<0.001	<0.001
3-Methylindole	ppm	<0.001	<0.001	0.004	<0.001	0.004
γ -Butyrolactone	ppm	7.159	8.710	88.217	23.006	5.135
Nonanal	ppm	<0.001	0.016	3.852	3.591	<0.001
Decane	ppm	<0.001	0.025	0.480	0.581	<0.001
Undecane	ppm	<0.001	0.288	2.135	2.006	<0.001
Dodecane	ppm	0.113	0.191	2.496	2.059	<0.001
Nonane	ppm	0.003	0.016	0.035	0.031	0.007
Tridecane	ppm	0.091	<0.001	2.389	0.882	<0.001
Tetradecane	ppm	0.115	<0.001	2.392	0.709	<0.001
1-Decene	ppm	<0.001	0.004	<0.001	<0.001	<0.001

[1]ou – odor units, representing the number of dilutions with odor free air needed for the odor sample to be barely detected by 50% of a human panel

Development of an odor prediction equation from chemical constituents and correlation of compounds with odor dilution threshold

Simple correlations were developed between odor dilution threshold and individual compounds (table 6). Hydrogen sulfide and ammonia were best correlated to odor (r = 0.26 and 0.25, respectively). All other compounds had correlations less than 0.2 with many below 0.1. However, as the odor prediction equation was developed, assessing the interaction of all compounds measured as a whole, rather than independently, ammonia dropped out of the equation.

Using the analytes quantified by GC-MS, an odor prediction equation was developed using stepwise regression procedures. All variables remaining in the final equation are significant at the $P<0.05$ level. The equation accounted for 24% of the variation in response observed ($R^2 = 0.24$). Removal of outliers from the data set resulted in no improvement in predictive capability. All analyte concentrations are expressed as parts per million (ppm).

Odor dilution threshold = 195.68315 + 857[hydrogen sulfide] + 7629[butyrate] + 3631[valerate] - 70700999[valerate^2] + 3283067691[valerate^3] - 187754840[4methylphenol^3] - 960469[4ethylphenol] + 797701066[4ethylphenol^2] - 1.49986E^{11}[4ethylphenol^3] - 550[decane^3] + 430962[nonane] - 2870843[nonane^2] + 199986[tridecane^2] - 2123349[tridecane^3] - 9761[tetradecane] + 84523[tetradecane^2]

Development of an odor prediction equation that considers the interactive effects of the compounds analyzed by GC-MS is also planned for the peer-reviewed manuscript that will result from this work.

Table 4. Probability levels for production phase and site within phase (farm) effects of concentrations of chemical constituents, odor, and particulates immediately outside of the building at each study site.

Measure	Production phase	Farm
Particulates		0.0272
Odor dilution threshold	0.2624	0.3557
NH_3	0.0874	0.0012
H_2S	0.8586	0.0366
Acetate	0.0141	0.0024
Propionate	0.6184	0.4414
Isobutyrate	0.0007	0.9700
Butyrate	0.0254	<.0001
Isovalerate	0.0166	0.0571
Valerate	0.0383	<.0001
Phenol	0.0395	<.0001

4-Methylphenol	0.0837	<.0001
4-Ethylphenol	0.8107	0.0004
Indole	0.5078	0.5823
3-Methylindole	0.1050	0.0660
γ -Butyrolactone	0.2250	0.0054
Nonanal	0.2067	<.0001
Decane	0.3754	0.3862
Undecane	0.1241	0.1250
Dodecane	0.0103	<.0001
Nonane	0.3332	0.2633
Tridecane	0.5435	0.6847
Tetradecane	0.6222	0.5275
1-Decene	0.7891	0.9489

Table 5. Least squares means of measures collected from the berm of the downwind side of lagoons at the breeding and gestation sites (0 m).

Analyte	*NH_3*	*H_2S*	*Acetate*	*Propionate*	*Butyrate*	*Phenol*	*γ – Butyrolactone*
	ppm	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
Sow A	0.625	0.069	25.699	0.052	0.177	0.058	24.278
Sow B	0.944	0.330	25.719	0.000	0.046	0.053	45.001

Analyte	*Decane*	*Nonanal*	*Undecane*	*Dodecane*	*Nonane*	*Tridecane*	*Tetradecane*
	ppm	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
Sow A	0.498	2.746	2.480	2.315	0.086	0.415	0.266
Sow B	0.335	3.124	1.177	1.436	0.031	0.819	0.559

Table 6. Correlation of odor dilution threshold with analytes measured by gas chromatography-mass spectrometry.

H_2S	0.26004	Valerate	0.07871	Decane	-0.02940
NH_3	0.23716	Phenol	0.07750	Undecane	-0.02617
Acetate	0.01245	4-Methylphenol	0.15521	Dodecane	-0.01655
Propionate	0.08459	4-Ethylphenol	0.11487	Nonane	-0.00346
*Iso*butyrate	0.01624	3-Methylindole	0.08100	Tridecane	0.01515
Butyrate	0.11375	γ-Butyrolactone	-0.00591	Tetradecane	-0.00144
*Iso*valerate	0.05707	Nonanal	-0.01779	1-Decene	0.01263

Estimating downwind concentrations of chemical constituents and odor concentration

Measurements collected at buildings and maure storages plus the measurements at distances downwind from the source location at each site were analyzed in a stepwise regression model in order to develop downwind prediction equation that were based on the source concentration. Coefficients for significant terms of each measurement are depicted in table 7. The equations were developed using all of the data, not distinguishing between production phases or site, thereby allowing the equations to be used for any swine operation. Climatic conditions (temperature and humidity) served as model parameters. For the peer-reviewed publication, solar cover will be converted to a numeric value, representing solar intensity, and included as a model parameter.

Both hydrogen sulfide and odor were predicted well (R^2 = 0.64 and 0.49, respectively). Because ammonia concentrations downwind were below the instrumental capabilities, it could not be predicted. The VFAs and phenols were also predicted reasonably well, given the variation within the study. The exception to this is

acetate, which was poorly predicted and did not include the source concentration in the final model. Similarly, the hydrocarbons (compounds ending in '-ane'), while resulting in reasonable r-squares, often did not include distance in the final model. As a result, confidence in the downwind predictability of these compounds is questionable at this time. Note that the importance of source concentration and distance from the source were the most important factors in determining downwind concentrations, overwhelming the contribution of temperature and humidity.

Discussion

Results show that management of a swine operation has greater influence on concentration of emitted gases than does type of production at the unit. For example, when comparing deep-pit finishing facilities to breeding and gestation operations with outside manure storage average hydrogen sulfide concentrations were similar for the two types of systems. However, within the eight finishing sites studied, hydrogen sulfide concentrations, represented as a statistical mean across two season's sampling, varied considerably. Odor dilution threshold measures were not different between swine production phases or sites. Though, numerically, the means appear different this is a reflection of day-to-day variation.

Large standard deviations in measurements from one sampling day to the next, make it difficult to predict concentrations on any given day. However, prediction equations were developed to estimate downwind concentrations based on the climatic conditions of the day, distance from the source, and source (building or manure storage) concentration.

Using odor, hydrogen sulfide and phenol as examples, the following table illustrates downwind concentrations under varying scenarios of source concentration (0 m), distance, temperature and humidity.

Table 8. Predicted downwind concentration of odor, hydrogen sulfide, and phenol under various scenarios.

Temp, F	Humidity, %	Source concentrations (0 m)				Downwind concentrations		
		Odor	H2S, ppm	Phenol, ppm	Distance, m	Odor	H2S, ppm	Phenol, ppm
80	65	250	0.150	0.400	200	86	0.017	0.099
80	65	250	0.150	0.400	100	134	0.005	0.079
65	65	250	0.150	0.400	100	134	0.011	0.112
65	40	250	0.150	0.400	100	134	0.011	0.234
65	40	125	0.080	0.200	100	35	<LOD	0.108

Notice that each compound responded differently to the scenario changes, indicating a need for compound-specific equations. Temperature changes did not affect odor concentrations much but decreasing temperature from 80° F to 65° F increased hydrogen sulfide and phenol concentrations, presumably due to less volatilization of those compounds in the cooler weather, Similarly, reducing humidity from 65% to 40% did not influence odor or hydrogen sulfide, but resulted in an increased downwind concentration of phenol. In all cases, changes to downwind distance and source concentrations resulted in a non-linear response (greater influence than a linear effect would have had).

Lay Interpretation

Air samples were collected or analyzed onsite from finishing, nursery and breeding and gestation operations twice weekly for a 10-wk period during each of two summers. Samples were analyzed for odor, hydrogen sulfide and additional specific gases (total of 21 gases routinely quantified) at both the building or manure storage area and approximately 50, 100, and 200 m downwind. Climatic conditions were recorded during each visit. From the collected data an odor prediction equation was developed based on the measured gases. Approximately 50% of the variation observed in odor could be accounted for by the developed equation. In addition, specific gases were individually correlated to odor to determine if any, individually, could serve as a

surrogate for odor. While hydrogen sulfide and ammonia were the two best indicators, each only accounted for approximately 25% of the odor response.

Equations were formulated to estimate downwind concentrations of the gases and odor, based on the concentration observed at the source. All equations were compound specific. Results indicate that climatic variables, while included, were not as important to predictive capability as was source concentration or distance downwind. Prediction equations for odor, hydrogen sulfide and the volatile fatty acids, a specific group of the analyzed gases, were reasonably capable of estimating downwind concentrations, accounting for as much as 64% of the response variation. For these compounds and odor, if a producer knew the source concentration the producer could estimate the property line concentration with a reasonable degree of certainty provided that distance to the property line, temperature and humidity were known.

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Analyte	Intercept	Source concentration	Source concentration^2	Source concentration^3	Distance	Distance^2	Distance^3	Temperature	Temperature^2	Temperature^3	Humidity	Humidity^2	Humidity^3	R^2
Odor dilution threshold	80.53	1.0015	-0.0006	1.48E-7	-2.1894	0.0057								0.49*
Hydrogen sulfide	0.1381	0.1618	0.2070	-0.0056	-0.0036	3.09E-5	-7.93E-8	-0.0004						0.64**
Acetate	247.76				-0.2378	0.0007		-3.4269		0.0001		-0.0038		0.05**
Propionate	0.4874	0.2656	0.0115	-0.0001	-0.0141	5.43E-5								0.47*
Isobutyrate	0.0001	0.2974			-3.19E-6	1.31E-8								0.30*
Butyrate	0.3656	0.3912	0.0221	-0.0015	-0.0169	1.55E-5	-4.24E-7							0.42*
Isovalerate	8.97E-5	0.2513			-2.71E-6	1.07E-8								0.26*
Valerate	0.0395	0.6418	-0.2335	0.0328	-0.0018	1.60E-5	-4.51E-8							0.32*
Phenol	0.1888	0.5750	0.1044	-0.0228	-0.0026	2.29E-5	-5.82E-8	-0.0022			0.0071	-0.0002	1.07E-6	0.55***
4methyl	0.051	0.311		-	-	2.11E-	-							0.31*

phenol	6	5		0.0049	0.0023	5	5.60E-8							
4ethyl phenol	0.0016	0.3278	-0.2578		-4.91E-5	2.04E-7								0.27*
3methyl indole	0.0010	0.9345	-23.3246	183.02	-4.89E-5	4.62E-7	-1.23E-9							0.44*
Butyrol act-one	184.74	0.5788						-1.6612			-0.7877			0.14*
Decane	12.28	0.9578	-0.0329	0.0005				-0.2939	0.0018				-7.27E-7	0.63*
Nonanal	7.2520	0.8903	-0.0023					-0.0669			-0.0274			0.45*
Undecane	219.45	2.3340	-0.0651	0.0005				-8.4105	0.1071	-0.0005			-2.59E-6	0.43*
Dodecane	233.62	1.1533	-0.0100					-8.9344	0.1145	-0.0005		-3.68E-4		0.34*
Nonane	23.05	-2.7238	2.2700	-0.2939	0.0004			-0.9073	0.0119	-5.13E-5			-1.78E-7	0.13**
Decene	-0.0022	1.6611	-0.6786				5.47E-9							0.08*
Tridecane	276.19	1.4123	-0.0259	0.0001	-0.0126		4.78E-7	-11.0583	0.1465	-0.0006			-1.33E-6	0.22*
Tetra-decane	1.5564	0.6486						-0.0236			0.0170		-1.79E-6	0.50***

*All individual terms are significant at P<.05.

** All individual terms are significant at P<.10.

*** All individual terms are significant at P<.15.

Note: All concentrations are in ppm, distance is in meters, temperature is in F, humidity is %.