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Survey of Hydrogen Sulfide Concentrations in Vicinity of Beef Cattle Feedlots

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Abstract. *A field survey of Total Reduced Sulfur (TRS) concentrations in the vicinity of beef cattle feedlots was conducted to compare field observations against current regulatory thresholds. In addition, environmental factors that may contribute to increased TRS emissions were evaluated. It was observed that TRS levels in the vicinity of beef cattle feedlots are not likely to exceed current regulatory thresholds used by mid-western states. It was further noted that concentration of TRS varies with air temperature and time of day. However, wet feedlot surface conditions and wind speed had almost no impact upon observed concentrations.*

Keywords. Hydrogen sulfide, beef cattle feedlots, air quality.

[1] The authors wish to acknowledge the efforts of Joel Stenberg and April Eisenhauer in the collection and analysis of the data for this project.

Introduction

Hydrogen sulfide (H_2S) and Total Reduced Sulfur (TRS) emissions from livestock systems are increasingly being implicated with community health related concerns. Occupation health hazards for H_2S for those working in confinement livestock production and other agricultural settings have long been recognized. Occupational exposure limits and recommendations for H_2S have been established by the American Conference of Governmental Industrial Hygienists (ACGIH), the American Industrial Hygiene Association, the National Institute for Occupation Health and Safety, and Occupational Health and Safety Administration in the range of 0.1 ppm to 20 ppm. However, community exposure to ambient levels of H_2S has gained increasing scrutiny in recent years. The Agency for Toxic Substances and Disease Registry, the federal agency charged with evaluating possible general public health risks form chemicals released at wastes sites has recently published recommended Minimal Risk Levels for H_2S in the range of 0.03 to 0.07 ppm.

In 1997, the Nebraska Department of Environmental Quality amended its Title 129 Air Quality Regulations to establish a regulatory threshold for Total Reduced Sulfur (TRS) concentrations under ambient conditions. These thresholds are set at "10.0 parts per million (10.0 PPM) maximum 1 minute average concentration or 0.10 parts per million (0.10 PPM) maximum 30-minute rolling average". Following the adoption of these rules, two agricultural regions of Nebraska with significant cattle finishing in open feedlots came under scrutiny for possible rule violations. In one situation, area feedlots were asked to prepare and implement a TRS control plan. State standards for H_2S or TRS have been set by 27 states (Janni et al., 2001).

Research Objectives

This growing scrutiny prompted a field survey of TRS levels in the vicinity of typical beef cattle feedlots in central Nebraska. The intent of this research is to:

1. Compare field observations from the vicinity of beef cattle feedlots against current regulatory thresholds for Nebraska (0.1 ppm TRS ½ hour average), Minnesota (0.03 ppm H_2S ½ hour average), and Iowa (proposed to be 0.07 ppm H_2S 1 hour average);
2. Identify environmental factors that influence TRS concentration.

The paper summarizes field observations of average TRS concentrations, number of observations exceeding regulatory threshold values, and observed relationships between TRS levels and time of day, air temperature and feedlot surface moisture conditions.

Literature Review

Hydrogen sulfide is a colorless, heavier than air, gas that has a characteristic rotten egg odor. High concentrations of H_2S are toxic to humans and animals. Concentrations of 50 ppm cause dizziness and other health while levels of 1,000 ppm cause respiratory paralysis and death with little or no warning. Historically, workplace threshold limits are set at 10 ppm (ACGIH, 1996) over an 8-hour day. Animal agriculture has experienced human deaths due to high concentrations of H_2S especially in confined spaces such as covered manure storages.

More recently, concerns are being raised about long term exposure of neighbors to substantially lower rates. Schiffman et al. (2001) concludes that a low concentration of H_2S and other gases and bio-aerosols associated with animal agriculture can potentially impact human health. The odor detection threshold of H_2S is 30 ppb or less for 83 % of the population and concentrations of less than 40 ppb annoy 50% of the population (Collins and Lewis, 2000). Elevated self-reported health symptoms are observed for ambient air containing H_2S between 7 and 27 ppb annual average (Legator, et al., 2001). An intermediate (15 to 364 day exposure) and an acute (1 to 15 day exposure) inhalation minimum risk level is defined at 30 and 70 ppb daily average exposure, respectively, by the Agency for Toxic Substances and Disease Registry (ATSDR, 1999).

Exposure to low concentrations has been the basis for property line or ambient air based H_2S regulation. Janni et al. (2001) identified 27 states that regulate H_2S or TRS levels. A wide range of state regulatory thresholds is reported. A property line concentration in the range of 30 and 100 ppb over a 30 to 60 minute averaging time is a common regulatory threshold (Janni et al., 2001).

Methionine, a common amino acid in many feedstuffs, is the origin of many sulfur-related odors (Hobbs and Pain, 1995). Sulfate compounds in the urine originate from degradation of protein sources such as methionine. Degradation of sulfate in the urine by sulfate reducing bacteria produces the odorous sulfides and mercaptans (Spoelstra, 1980). A reduced crude protein diet supplemented with synthetic amino acids, including methionine, to meet but not exceed, animal protein needs reduces room aerial H_2S concentrations by 40% (Kendall et al., 1998). Arogo, et al., 2000 observed that initial sulfate concentration in the manure impacted H_2S production and suggested that reducing sulfate concentration in the water supply would also help reduce the sulfide production.

In addition, many environmental and management factors affect the release or concentration of H_2S. Heber and Heyne (1999) observed that H_2S levels as measured at a property line for a wean to finish swine facility was twice as high at night as during the day and that high wind speeds (greater than 29 km/hr) increased emission rates from a lagoon surface. H_2S levels were only 13% of mean concentrations based upon observations before and after installation of a geotextile/straw cover (Heber and Heyne, 1999). Average H_2S emissions from a manure storage facility for a swine finishing operations was reported to range from less than 5 to 30 $\mu g/(m^2\text{-}s)$ for a storage surface with a natural crust to 20 to almost 100 $\mu g/(m^2\text{-}s)$ for a storage surface lacking a natural crust (Bicudo, et al., 2001). Agitation of pit swine manure causes substantial short-term increases in H_2S emissions levels (Tengmann, 2001).

A growing data base on H_2S concentration and emission rates for swine facilities is available (Ni et al., 2000, Zahn et al., 2001, Parbst, 2000, Wood et al., 2001 and Zhu et al., 2000). A limited database is available for cattle facilities. Zhu et al. (2000) reported H_2S concentrations in dairy buildings ranging from 8 to 26 ppb as compared to levels in swine nursery and gestation buildings ranging from 500 to 3400 ppb. A mean H_2S emission rate of 1.72 $\mu g/(m^2\text{-}s)$ was reported for open lot beef facilities as compared to 14 $\mu g/(m^2\text{-}s)$ for swine finishing barns in Minnesota (Wood, et al., 2001). Carlisle (1998) reported H_2S measurement at the property line of one Texas cattle feeding operation and suggested a maximum 30-minute concentration of 6 ppb as compared to a maximum of 10 to 43 ppb for six swine operations.

Measurement of H_2S is possible with an indicator or diffusion tube (1000 ppb and greater), Jerome meter (3 ppb and greater), or MDA single-point monitors (2 to 90 ppb) (Jacobson et al., 2001). Winegar and Schmidt (1998) observed that the Jerome 631-X portable H_2S unit's "gold film sensor is affected by sulfides other than H_2S." They further suggest "field testing for mixed sulfides by collecting field data with the Jerome 631-X (and reporting) as total sulfides."

Response factors for this meter was 100% for H_2S and generally less than 50% for 11 other sulfur-containing compounds. The study further reported a reliable detection level of 1 ppb and excellent agreement between the Jerome meter and GC standard methods over a range of 0 to 40,000 ppb (R2 = 0.9998, slope = 0.9832).

Single gas measurements, as an indicator of odors is a common pursuit of many individuals. O'Neill and Phillips (1992) list 15 sulfide compounds and 9 mercaptans that are among the 160 compounds identified in animal waste or air around livestock buildings. This reports further notes that six of the 10 compounds with the lowest odor detection threshold contain sulfur. Guo (2000) identified a correlation coefficient of r^2= 0.569 (1152 air samples from 260 sources on 80 Minnesota livestock and poultry farms) and concluded that H_2S is a generally a poor odor indicator but have value for species and facility specific situations. Jacobson et al. (1997) and Fakhoury (2000) also noted low correlation coefficients. Williams (1984) suggests that sulfide is a misleading indicator of offensiveness of odor from pig slurry during anaerobic treatment but is a useful indicator during post-treatment storage.

Procedures

A field survey was implemented to provide a preliminary review of TRS emissions in the vicinity of feedlots. Two Jerome 631-S analyzers with memory modules and a dynamic range of 1 ppb to 50 ppm were used to survey TRS concentrations at 15-minute intervals approximately 1 meter from the ground surface. An on-site meteorological weather station (MicroMet Station) was used to collect wind speed, wind direction, air temperature, barometric pressure, and relative humidity at 15-minute intervals.

The Jerome meter responds to H_2S, alkyl sulfides, disulfides, mercaptans, and cyclic sulfur compounds. Winegar and Schmidt (1988) showed that the response of the Jerome 631-X meter was 100% to H_2S and 0 to 45% to other reduced sulfur gases when exposed to calibrated mixtures. The meter response is calibrated to an H_2S equivalent. The data presented in our paper are described as TRS and represents an H_2S equivalent measure. We made no effort to identify specific reduced sulfur gases during our field survey.

A Jerome meter reading of H_2S equivalents should almost always provide a conservation (high) estimate when compared to both TRS and H_2S regulatory standards. A comparison of a Jerome meter reading (measuring an H_2S equivalent) against a TRS based regulatory standard produces a conservative (high) estimate if most of the TRS is in the form of H_2S. TRS, reported as elemental sulfur, has a molecular weight of 32.050 while H_2S has a molecular weight of 34.076 (Bolz and Tuve, 1973). Thus, a Jerome meter reading would overestimate TRS by 6% if TRS is dominated by H_2S. The Nebraska Department of Environmental Quality has found Jerome meter readings to be an acceptable measure for comparing against a TRS based standard. When comparing the Jerome meter reading against a H_2S regulatory standard, the Jerome meter will always overestimate actual H_2S. The Jerome meter converts some non-H_2S volatile sulfur compounds into an H_2S equivalent. In situations where H_2S is the dominant TRS, this overestimate becomes negligible.

Surveys were conducted on three feedlots for one-week periods each under spring, summer and fall conditions during 2000. During this investigation, sampling was completed at the following locations:

- A perimeter survey was conducted upon arrival, departure, and often during the one week sampling period. TRS measurements were taken at 0.2-mile intervals on all four township mile lines surrounding the feedlot. Only two to four observations were made at each location during each visit.

- Within the feedlot, data were collected at the center point within the feedlot among the animal pens, at the downwind edge of the feedlot, and at the downwind edge of the runoff holding pond. The downwind feedlot and holding pond edge locations were selected based upon prevailing wind conditions for the nearest local weather station and the five-day weather forecast. All data from a downwind measurement location was included in the analysis, not just the data collected when the wind was blowing from the facility toward the meter. Typically, one Jerome meter was located at the center of the feedlot for the entire week and the second meter was moved among the three locations for two to three day intervals. Measurements were made at 15-minute intervals at these three locations.

A second survey was conducted in 2001 to identify environmental factors that increased the emission of TRS. Two 9-week surveys were conducted during the spring (April 4 through June 9) and summer (July 9 through September 12) of 2001 at a single location at the center of one feedlot with one Jerome meter. During the sampling period, on-site weather data were collected at 15-minute intervals and were matched with TRS observations collected at similar time intervals.

To evaluate field observations against regulatory thresholds, three state regulations were used:

- Nebraska: Property line TRS concentrations shall not exceed10.0 ppm maximum, 1-minute average concentration or 0.10 ppm maximum, 30-minute rolling average.
- Iowa (proposed rule): Property line H_2S concentrations shall not exceed 0.07 ppm for a 1-hour time weighted average (Merchant and Ross, 2002). For consistency with the NE and MN regulatory thresholds, a 30-minute average was used for comparison against field observations.
- Minnesota: H_2S concentrations shall not exceed 0.03 ppm for a 30-minute average concentration (twice in 5 days) or a 0.05 ppm for a 30-minute average concentration (twice per year). The first standard (0.03 ppm) was used for comparisons.

Results

Perimeter Observations

To determine the impact of feedlot TRS emissions on the community, a survey of neighborhood concentrations was completed on the township mile lines surrounding the feedlot. Those observations are summarized in Figure 1. The average TRS levels at these locations ranged from 0.002 to 0.006 PPM (parts per million by volume) for all three feedlots. The peak observation was 0.030 PPM, below the regulatory thresholds for Nebraska and Iowa (proposed). The 0.030 PPM reading was observed at a location approximately one mile from the feedlot and based upon other observations and readings at nearby locations, it appeared to be an isolated observation not related to the feedlot. Other higher than normal values were from locations directly adjacent to the feedlot facilities. However, these values did not exceed even the most stringent regulatory thresholds.

Very little variation in average TRS levels were observed for perimeter measurements more distant from the feedlot compared to those immediately adjacent to the feedlot. Average

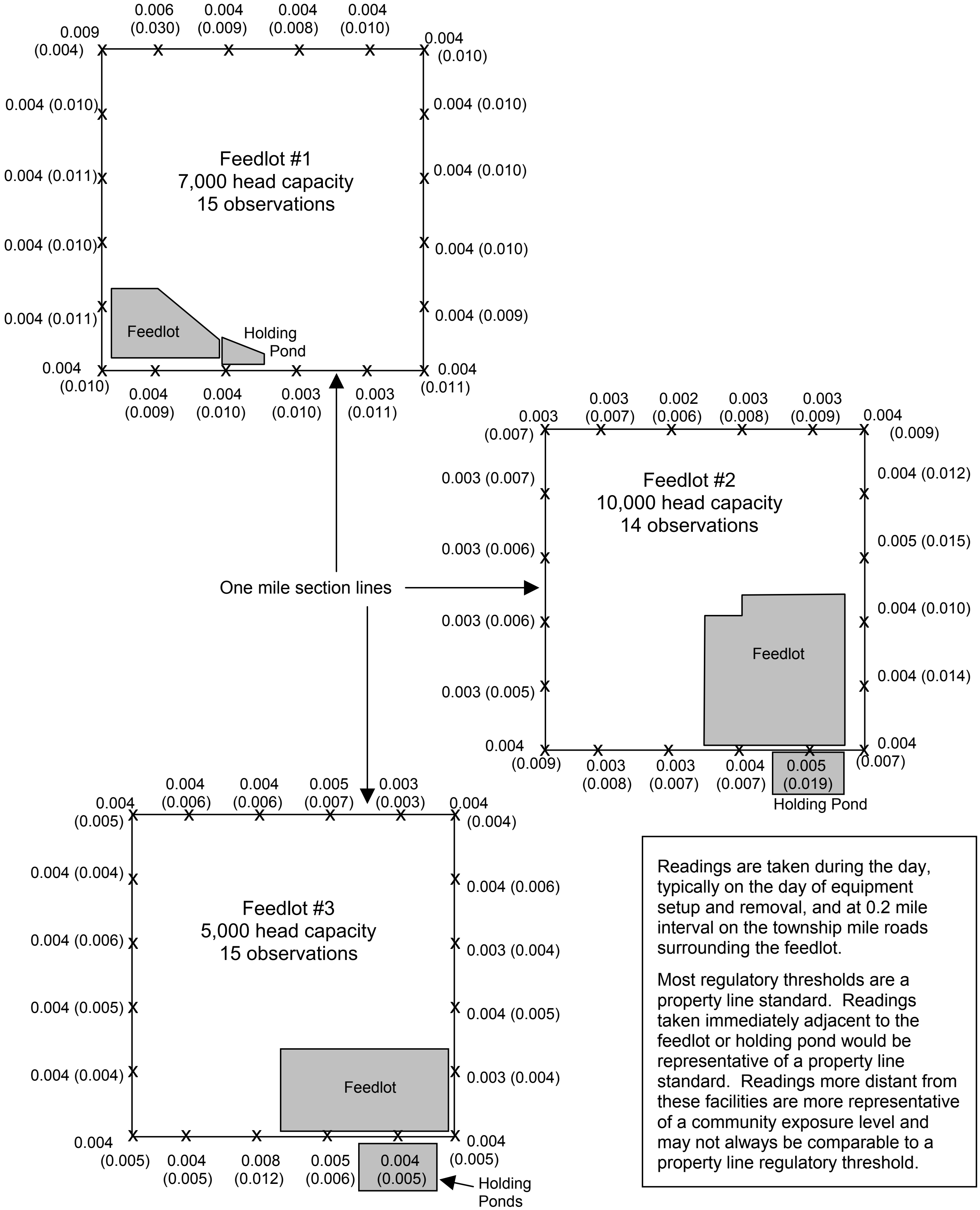

Figure 1. Summary of average (and maximum) TRS observations at perimeter of feedlots (parts per million). TRS is expressed as a equivalent H_2S concentration.

TRS levels on locations immediately adjacent to the feedlots were within 0.002 PPM of the averages observed at more distant locations. The perimeter observations provided no indications of TRS levels that might exceed regulatory thresholds.

Approximately 3,700 observations were made at a location a few meters immediately downwind (based upon prevailing winds) from the feedlot and holding pond (Table 1). Only two observations exceeded Nebraska's 10 ppm, 1-minute standard, both at the edge of the holding pond. The 30-minute running averages exceeded Nebraska's 0.1 ppm, 30-minute standard on 36 occasions (15 and 21 occurrences at the edge of the feedlot and holding pond, respectively). However, the calculated running average from this survey was based upon 3 data points and often heavily influenced by a large single observation. No situations were observed where three consecutive readings exceeded Nebraska's 0.1 ppm, 30-minute standard.

A comparison of these results against the proposed Iowa standard (0.070 ppm, 30-minute average) suggests that single point observations exceed this level at similar rates as observed for the Nebraska standard. However, the single point observations exceeded the Minnesota standard (0.030 ppm, 30-minute average) three times more frequently. In addition, the 30-minute running average data from the feedlots (based upon 3 points) often exceeded the Iowa (47 times) and Minnesota (104 standard). However, sustained TRS concentrations above these standards for 30 minutes were extremely rare (1 observation exceeding the Minnesota standard).

Based upon observations at the edge of the feedlot and holding pond, few differences were observed among the three feedlots. Average TRS concentrations were similar with most averages being less than 0.01 ppm. Feedlot 1 experienced more single point observations above common regulatory thresholds at the feedlot edge location. Feedlot 2 experienced higher rates of observations above these thresholds at the holding pond edge. However, average TRS concentrations were similar among all three feedlots and all were low relative to regulatory thresholds and ATSDR defined minimum risk levels based upon inhalation.

Feedlot Center Observations

At the center of the feedlot, spikes in TRS concentration that may exceed a property line threshold were common, but sustained levels (30 minute periods) were very uncommon except at the lowest regulatory threshold. More than 18,200 observations were made at the center of the feedlots. 63 single point observations exceeded a 0.1 PPM level. However, even at the center of the feedlot sustained TRS levels exceeding the 0.1 ppm (2 occurrences or 0.01 % of observations) and 0.07 ppm (6 occurrences or 0.03% of observations) for a one half hour period were very infrequent. Sustained levels (1/2 hour period) above 0.03 ppm were more common (183 occurrences or 1% of observations). All occurrences exceeding the 0.03 ppm level were from feedlot 2. The feedlot surface would not appear to be a sustained source of TRS that might lead to property line regulatory concerns.

Several environmental factors have the potential to impact TRS concentrations. TRS levels increased linearly with air temperature between 0 and 35ºC (Figure 2). A 20ºC rise in air temperature correlated to a doubling of observed TRS concentration. Increased soil temperatures should contribute to increased soil microbial activity and greater production of volatile sulfur compounds. Soil temperature, not measured in this experiment, would be expected to track changes in air temperature.

Table 1. Summary of TRS[a] observations within three Nebraska feedlots.

	Feedlot #1			Feedlot #2			Feedlot #3					Total
	Spr	Sum 2000	Fall [c]	Spr	Sum 2000	Fall	Spr	Sum 2000	Fall	Spr 2001	Sum 2001	
Center of Feedlot												
Single observations:												
> 10 PPM	0	0	0	0	0	0	0	0	0	0	0	0
> 0.1 PPM	7	3	0	17	3	10	1	13	3	3	3	63
> 0.07 PPM	8	3	0	24	3	22	1	13	3	3	3	83
> 0.03 PPM	40	7	0	271	41	68	2	20	3	4	3	459
Running Average:												
> 0.1 PPM	6	0	0	17	1	2	0	8	3	0	0	37
> 0.07 PPM	12	3	0	31	5	13	0	21	3	0	3	91
> 0.03 PPM	44	9	0	257	29	84	3	42	3	0	9	480
3 consecutive observations[b]:												
> 0.1 PPM	0	0	0	2	0	0	0	0	0	0	0	2
> 0.07 PPM	0	0	0	4	0	2	0	0	0	0	0	6
> 0.03 PPM	0	0	0	141	18	24	0	0	0	0	0	183
Average TRS concentration[a]	0.010	0.012	0.001	0.028	0.037	0.009	0.006	0.014	0.002	0.006	0.008	
Number of observations	902	320	190	904	683	640	1249	558	854	5803	6115	18,218
Feedlot Edge												
Single observations:												
> 10 PPM	0	0	0	0	0		0	0				0
> 0.1 PPM	9	1	0	1	0		0	4				15
> 0.07 PPM	9	1	0	1	0		0	4				15
> 0.03 PPM	13	8	0	5	0		0	4				30
Running Average:												
> 0.1 PPM	9	0	0	0	0		0	6				15
> 0.07 PPM	12	0	0	0	0		0	7				19
> 0.03 PPM	31	7	0	6	0		0	10				54
3 consecutive observations[b]:												
> 0.1 PPM	0	0	0	0	0		0	0				0
> 0.07 PPM	0	0	0	0	0		0	0				0
>0.03 PPM	0	0	0	0	0		0	0				0
Average TRS concentration[a]	0.013	0.009	0.005	0.007	0.006		0.008	0.008				
Number of observations	251	343	496	184	176		118	180				1748
Holding Pond Edge												
Single observations:												
> 10 PPM	1	0		0	1	0	0	0				2
> 0.1 PPM	2	2		1	4	0	1	3				13
> 0.07 PPM	2	2		2	4	0	1	3				14
> 0.03 PPM	3	2		10	5	0	18	6				44
Running Average:												
> 0.1 PPM	6	3		0	9	0	3	0				21
> 0.07 PPM	6	3		0	10	0	3	6				28
> 0.03 PPM	6	6		9	10	0	10	9				50
3 consecutive observations[b]:												
> 0.1 PPM	0	0		0	0	0	0	0				0
> 0.07 PPM	0	0		0	0	0	0	0				0
>0.03 PPM	0	0		1	0	0	0	0				1
Average TRS concentration[a]	0.001	0.009		0.009	0.006	0.002	0.012	0.008				
Number of observations	228	255		355	283	353	283	185				1942

[a] TRS is reported as parts per million H_2S equivalent .

[b] Three consecutive observations at 15-minute intervals would approximate situations where TRS levels exceeded the 0.1 PPM 30-minute average regulatory threshold for Nebraska.

[c] Most observations occurred after a six-inch blowing snow.

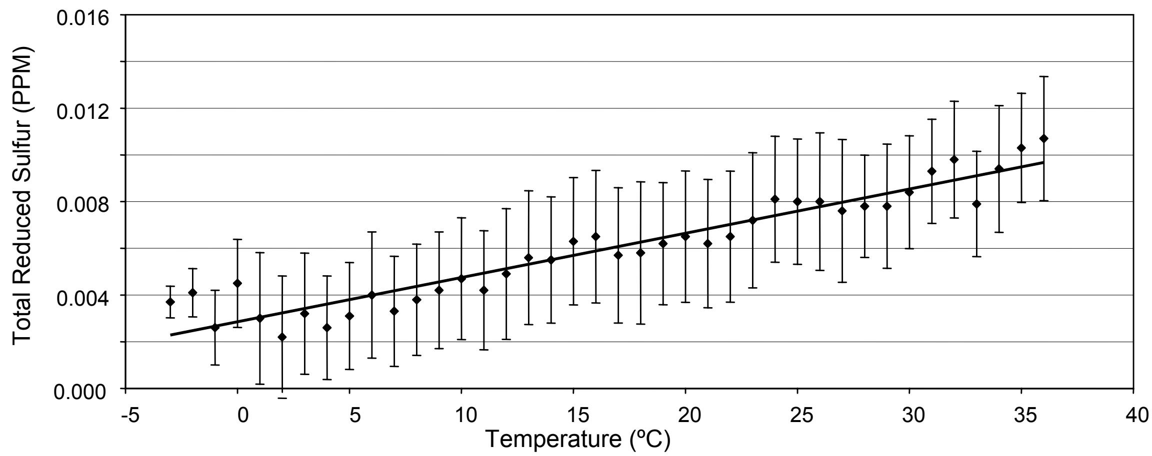

Figure 2. Average TRS concentration (± one standard deviation) vs. air temperature for feedlot #3 during spring 2001. TRS is reported as an H_2S equivalent.

Wind speed generally impacts observed gaseous emissions concentrations. With increased wind speed causing increased atmospheric instability and greater mixing of feedlot emissions with fresh air, lower concentrations of TRS would be anticipated. However, mean TRS concentrations at the center of the feedlot showed little variation with increases in wind speed (Figure 3).

A strong diurnal pattern was observed for TRS concentration (Figure 4). Peak concentrations were observed during mid-afternoon and the lowest concentrations occurred during early morning hours. Afternoon concentrations were approximately twice those observed during the early morning. Several factors would likely impact daily TRS concentrations. Typically, wind speed and stability of the air influences dilution of volatile emissions. However, evening and early morning hours when conditions contributing to the least dilution and greatest concentration would be anticipated was the period when the lowest TRS concentrations were

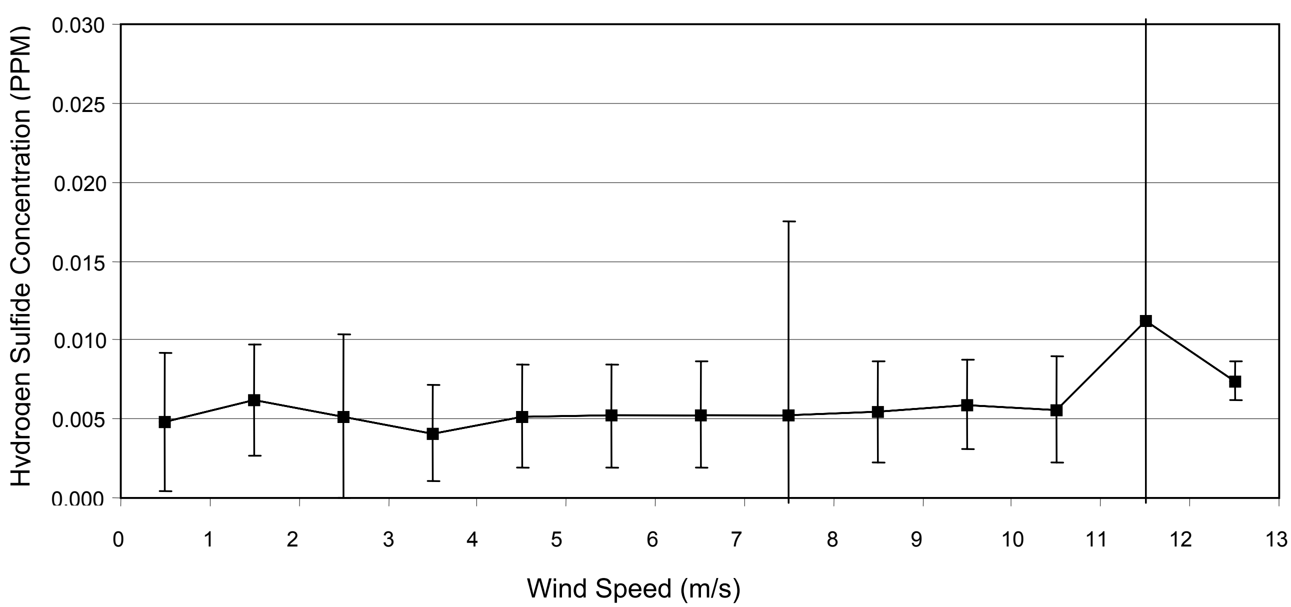

Figure 3. TRS concentration (reported as an H_2S equivalent) at various wind speeds on feedlot #3 during spring 2001.

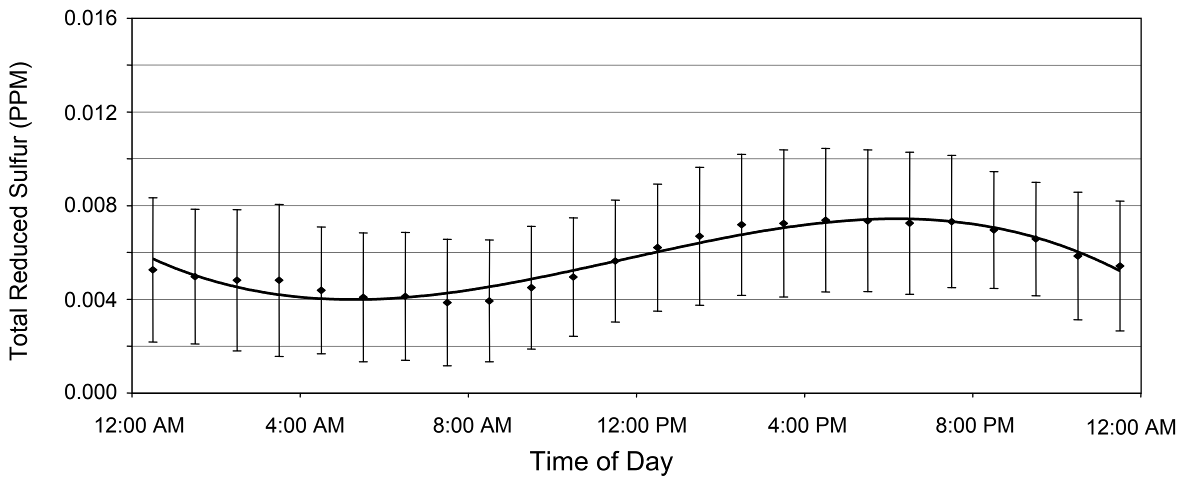

Figure 4. Average TRS concentration (reported as an H_2S equivalent) vs. time of day for feedlot #3 during spring 2001.

observed. Greater instability and more dilution are typically expected during mid-day conditions. However, TRS levels were generally increasing during the period of typically greater air mass instability (mid day) and peaking during late afternoon. Other factors as opposed to air mass stability must be influencing the observed diurnal pattern

Soil temperature and animal activity may provide a more plausible explanation of this diurnal pattern. Soil surface temperature, which impacts microbial action and TRS production, would increase during daylight and decline during the night similar to the pattern observed for TRS. Figures 1 and 5 provide additional indications that TRS level is related to air temperature. Animal activity would tend to increase during the morning hours as a result of feeding practices and during late afternoon and evening hours as evening temperatures cool. The late afternoon TRS peak is at a similar time to the late afternoon peak in animal activity. Peaks in animal activity are commonly correlated with feedlot dust emissions (Auverman, 2001). Thus, soil temperature and animal activity are more likely factors contributing to the observed diurnal TRS levels at the feedlot's center.

It was anticipated that feedlot surface moisture level would influence TRS concentration. Wet feedlot conditions, conducive to bacterial activity, and anaerobic conditions should result in greater TRS production. Feedlot surface conditions in Nebraska vary dramatically based upon weather conditions. The extended sampling during the spring and summer of 2001 was conducted in hopes of capturing the effects of volatile sulfur production under muddy feedlot surface conditions.

Six rainfall events occurred during the spring and summer 2001 sampling periods. TRS levels between 3 days prior to and 6 days after significant (>15mm) rainfall events are summarized in Table 2. For much of the early spring 2001, wet feedlot conditions were common. Summer feedlot surface conditions were typically very dry with short wet periods following a rainfall event. The TRS concentration for the days following rainfall events did not rise above the levels observed prior to or on the day of rainfall events (see Figure 5 and Table 2). No increase in TRS levels could be attributed to wet feedlot conditions.

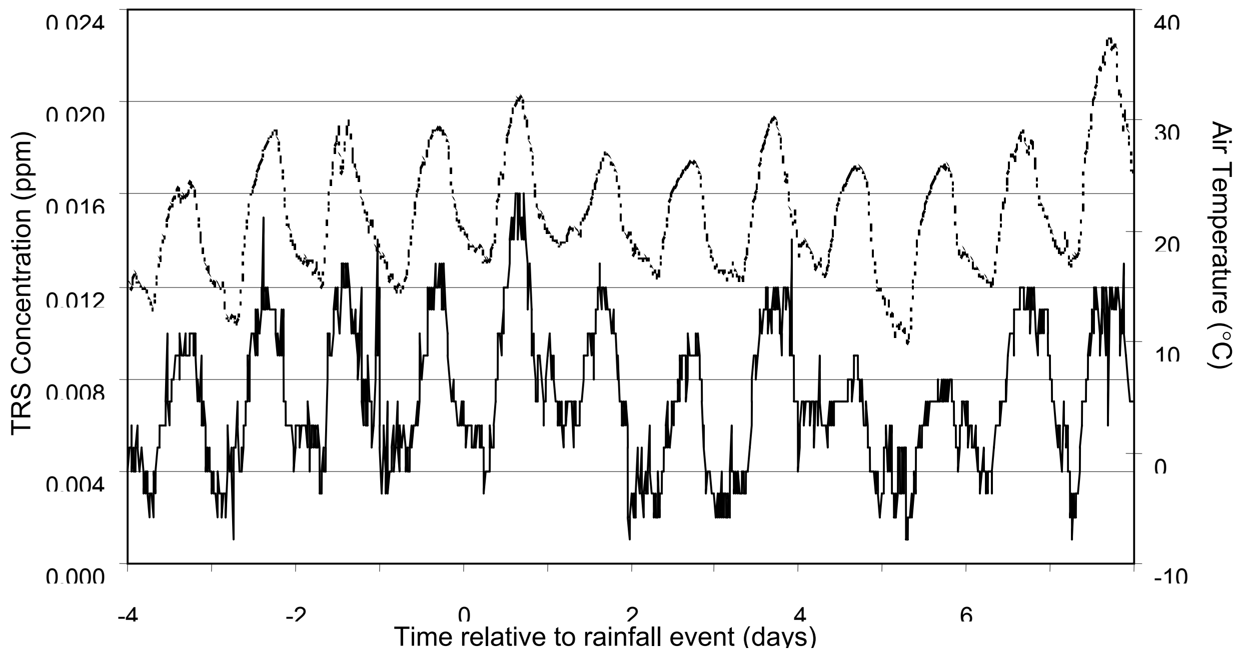

Figure 5. Impact of rainfall on TRS concentration for feedlot #3 (Event 5, August 10 –21). TRS is reported as an H_2S equivalent.

Table 2. Summary of daily TRS[1] level relative to rainfall events at feedlot #3 in 2001.

Day	Event 1		Event 2		Event 3		Event 4		Event 5		Event 6	
	April 7 - 16		May 1 - 10		May 17 - 26		May 27 – June 5		Aug. 11 - 20		Aug. 20 - 29	
	Rainfall (mm)	Average TRS (PPM)	Rainfall (mm)	Average TRS (PPM)	Rainfall (mm)	Average TRS (PPM)	Rainfall (mm)	Average TRS (PPM)	Rainfall (mm)	Average TRS (PPM)	Rainfall (mm)	Averag e TRS (PPM)
-3	0.4	0.004	0.8	0.007		0.008		0.008		0.007		0.008
-2	0.1	0.003	14.9	0.006		0.007		0.007		0.008		0.008
-1		0.004	5.2	0.006	1.2	0.007	9.6	0.006		0.007		0.007
0	16.0	0.002	72.9	0.004	17.7	0.007	40.4	0.007	26.0	0.009	20.0	0.007
1	5.8	0.003	9.1	0.007		0.007		0.007		0.008		0.007
2		0.003		0.007	0.7	0.007	0.1	0.006		0.005		0.006
3		0.002		0.004		0.006		0.006		0.007		0.006
4		0.003			0.2	0.005	17.9	0.007		0.006		0.007
5						0.007	2.2	0.003		0.005		0.007
6	0.2	0.007				0.008	1.2	0.006		0.008		0.006

[1] TRS concentrations are reported as an H_2S equivalent. See Procedures section.

Discussion

Based upon TRS observations at the prevailing downwind edge of the feedlot and holding pond as well as those on the mile lines surrounding the feedlots, it appears unlikely that feedlots produce sufficient TRS to exceed common regulatory thresholds. However, peak concentrations occasionally exceed common regulatory levels where the feedlot or holding pond is located at a property line. These peak concentrations often resulted in a 30-minute running average exceeding a regulatory threshold. However, this survey's computation of a 30-minute running average based upon only three data points, allowed one peak value to commonly produce a 30-minute running average in excess of a regulatory threshold. With extremely few exceptions, these peak concentrations are not sustained over a 30-minute period. Sustained levels of TRS at the perimeter of the feedlot and holding pond above the any of the three state regulatory thresholds, including the more stringent Minnesota regulation, were rare.

A comparison of TRS observations at the perimeter (downwind feedlot and holding pond edge) and within the community (one mile township roads) with established health risk levels reveals little reason for concern. The Agency for Toxic Substances and Disease Registry (ATSDR) defined minimum risk levels for intermediate (0.030 ppm for 15 to 364 day) and acute exposures (0.07 ppm for 1 to 15 day) were not exceeded at any of the three feedlots.

One weakness of this study is that community measures of TRS (made on the mile lines surrounding the feedlot) represent a limited number of observations made during the day. Typically, the atmospheric conditions are least stable during day time conditions resulting in greater dispersion of any gaseous emissions and lower measures of concentration. Higher night time concentrations would be anticipated. However, observations at the edge of the feedlot and holding pond which were made continuously at 15 minute intervals provided no indication of a sufficient source of TRS to cause significant changes in TRS observations in the community.

Emissions from the feedlot surface where cattle are housed appear to be a minor source of TRS. Single high observations (above 0.1ppm) were commonly observed at the center of the feedlot, but these elevated levels were not sustained. It may be possible that short bursts of TRS are emitted from the feedlot surface, but that these bursts are not sustained. As a result, average TRS levels even at the center of the feedlot were fairly low, ranging from 0.006 to 0.037 ppm. The cause of these short periods of high TRS levels is unknown. Variation in animal activity in the vicinity of measurement point might be one explanation these high short term TRS levels. If true, future efforts to measure emissions rate for various gases from the feedlot surface should attempt to capture the animal activity factor as part of the emission measurement. Animal activity is known to be a critical factor in dust emissions (Auvermann, 2001).

Air temperature was the only observed environmental factor to which TRS concentration was correlated based upon observations at the center of the feedlot. Increases in temperature produced an increased TRS level. Daily TRS patterns also closely followed daily air temperature patterns. Wind speed showed no effect on TRS levels at the feedlot center.

TRS levels were scrutinized during the periods immediately following rainfall events for increased TRS concentrations, but no measurable increase in TRS was observed. Rainfall events should have stimulated anaerobic decomposition and produced fermentation products that sulfate-reducing bacteria (SRB) utilize. It is likely that a combination of environmental factors limit the abundance and activity of SRB at cattle feedlots, which accounts for the low H_2S concentrations after rainfall events. The feedlot soil is a very dynamic environment experiencing extremes in moisture, temperature, and substrate availability, which likely select against SRB. In general, SRB are strictly anaerobic microorganisms that require relatively simple substrates, such as lactate, short-chain VFA, and alcohols (Widdel, 1988), but are unable to compete with faster-growing fermentative microorganisms for more complex substrates (polysaccharides and proteins) that comprise manure (Miller and Varel, 2000).

Sulfate availability may also limit the potential activity of SRB, although feedlot soil sulfate levels are unknown.

Experiments with pure cultures suggest that SRB are oxygen intolerant and able to withstand oxic conditions for only several hours before vegetative cells die off. Feedlot soils experience much longer periods of oxic conditions. Cycles of wetting and drying select for soil bacteria that are more desiccation resistant than other bacteria. Bacteria that can form endospores similar to *Clostridium* and *Bacillus*, which appear to be dominant feedlot soil bacteria (Ouwerkerk and Klieve, 2001), would have an advantage over other bacteria. Only one group of bacteria within the SRB, the *Desulfotomaculum*, is capable of spore formation, but they tend to have higher optimum growth temperatures (>35 °C) than the more oxygen-sensitive, nonspore-forming SRB (Castro et al. 2000). Although no single factor (substrate availability, oxygen intolerance, or moisture and temperature extremes) would completely inhibit SRB activity, it is likely that the combination of these factors acts to control sulfate reduction in the cattle feedlot soils examined.

A strong diurnal pattern in TRS concentration was observed. It follows a similar pattern as air temperature. It is anticipated that increased soil temperature enhances fermentation processes, thus impacting the production and release of what little TRS there was. Animal activity level may also provide some explanation for higher afternoon TRS levels. If other gaseous and odor emissions follow similar patterns to TRS, it will be important to recognize this diurnal pattern in emission rate measurements.

Conclusions

Based upon the observations made in this survey of Total Reduced Sulfur (TRS) concentrations (expressed as a hydrogen sulfide equivalent) in the vicinity of cattle finishing feedlots, the following conclusions were drawn:

- Sustained levels of TRS at the township mile lines and prevailing downwind edge of the feedlot and holding pond above the regulatory thresholds for Nebraska, Iowa (proposed) and Minnesota, were extremely rare. TRS concentration in the vicinity of beef cattle feedlots are unlikely to exceed common regulatory thresholds or health risk levels identified by ATSDR.
- TRS levels increase linearly with increasing air temperature. It is anticipated that warming of feedlot surface is partially responsible for the increased production of TRS.
- A diurnal pattern was observed for TRS concentrations with peak levels occurring in mid-afternoon. This pattern is also likely attributable to varying feedlot surface temperature and possibly animal activity.
- TRS level was not influenced by rainfall events or wind speed. Transiently wet feedlot surface conditions do not appear to increase TRS emissions.

References

ACHIH. 1996.Threshold limit values for chemical substances and physical agents and biological exposure indices. Published by ACGIH. Cincinnati, OH. 138 pages.

ATSDR. 1999. Toxicological profile for hydrogen sulfide. U.S. Department of Health and Human Services, Public Health Service. Agency for Toxic Substances and Disease Registry.

Arogo, J., R.H. Zhang, G.L. Riskowski and D.L. Day. 2000. Hydrogen Sulfide Production From Stored Liquid Swine Manure: A Laboratory Study. Transactions of the ASAE. Vol. 43(5) 1241-1245.

Auvermann, B. 2001. Controlling dust and odor from open lot livestock facilities. Lesson 42 from Livestock and Poultry Environmental Stewardship curriculum. MWPS. Ames, IA. 26 pages.

Bicudo, J. R., D. R. Schmidt, C. L. Tengman, W. Powers, L.D. Jacobson and C. J. Clinton. 2001. Odor and Gas Emissions From A Naturally Crusted Swine Manure Storage. ASAE Meeting Presentation Paper No. 014092. ASAE Annual International Meeting, Sacramento, CA, July 30-August 1, 2001.

Bolz, R. E. and G. L. Tuve. 1973. Handbook of tables for applied engineering science. CRC Press. Cleveland OH.

Carlisle, L. 1998. Internal memo titled "Toxicology Evaluations of Air Monitoring Results, Hydrogen Sulfide and Ammonia, Concentrated Animal Feeding Operations, Ochiltree County" and report from L. Carlisle, Toxicology and Risk Assessment Section to Brad Jones, Director for Texas Natural Resources Conservation Commission. Dated November 19, 1998.

Castro, H. F., N. H. Williams, and A. Ogram. 2000. Phylogeny of sulfate-reducing bacteria. FEMS Microbiol. Ecol. 31:1-9.

Collins, J. and D. Lewis. 2000. Hydrogen Sulfide: Evaluation of Current California Air Quality Standards With Respect to Protection of Children. Prepared for California Air Resources Board, California Office of Environmental Health Hazard Assessment, September 1. http://oehha.ca.gov/air/toxic_contaminants/AQAC1.html#download.

Fakhoury, K. J., A. J. Heber, P. Shao and J. Q. Ni. 2000. Correlation of Odoe Detection Thresholds With Concentrations of Hydrogen Sulfide, Ammonia and Trace Gases Emitted From Swine Manure. ASAE Meeting Presentation Paper No. 004047. ASAE Annual International Meeting, Milwaukee, WI, July 9-12, 2000.

Guo, H., L. D. Jacobson, D. R. Schmidt and R. E. Nicolai. 2000. Correlation of Odor Dilution Threshold and H_2S and NH_3 Concentrations for Animal Feedlots. ASAE Meeting Presentation Paper No. 004043. ASAE Annual International Meeting, Milwaukee, WI July 9-12, 2000.

Heber, A.J. and M.J. Heyne. 1999. Outdoor Hydrogen Sulfide Concentrations Near A Swine Feeding Facility. Presentation at ASAE/CSAE-SCGR International Meeting, Toronto, Ontario, Canada. ASAE Meeting Presentation Paper No. 994006.

Hobbs, P. and B. F. Pain. 1995. Odor reduction in fresh pig slurry by dietary manipulation of protein. International Livestock Odor Conference '95. Ames Iowa. Iowa State University College of Agriculture. p. 5-7.

Jacobson, L., J. Lorimor, J. Bicudo, and D. Schmidt. 2001. Emission from Animal Production. Lesson 40 of Livestock and Poultry Environmental Stewardship curriculum. MWPS, Ames, IA. 29 pages.

Jacobson, L. D., C. J. Clanton, D. R. Schmidt, C. Radman, R. E. Nicolai and K. A. Janni. 1997. Comparison of Hydrogen Sulfide and Odor Emissions From Animal Manure Storages. In Proc. Ammonia and Odour Control From Animal Production Facilities. 405-412, eds. J. A. M. Voermans, and G. Monteny. Rosmalen, Netherlands: Dutch Society of Agricultural Engineering (NVTL).

Janni, K., L. Jacobson, D. Schmidt, S. Wood and B. Koehler. 2001. Livestock and Poultry Odor Workshop. University of Minnesota, Department of Biosystems and Agricultural Engineering.

Kendall, D. C., K. M. Lemenager, B. T. Richert, A. L. Sutton, J. W. Frank and B. A. Belstra. 1998. Effects of Intact Protein Diets Versus Reduced Crude Protein Diets Supplemented With Synthetic Amino Acids on Pig Performance and Ammonia Levels in Swine Building. J. Anim. Sci. 76 (Suppl. 1):173. (Abstract)

Legator, M. S., C. R. Singleton, D. L. Morris and D. L. Phillips. 2001. Health Effects From Chronic Low-Level Exposure to Hydrogen Sulfide. Arch. Environ. Health 56: 123-137.

Merchant, J. A. and R. F. Ross. 2002. Iowa concentrated animal feeding operations air quality study. Final report of Iowa State University and the University of Iowa Study Group. http://www.public-health.uiowa.edu/ehsrc/CAFOstudy.htm. 221 pages.
Miller, D. N., and V. H. Varel. 2001. In vitro study of the biochemical origin and production limits of odorous compounds in cattle feedlots. J. Anim. Sci. 79:2949-2956.
Ni, J. Q., A. J. Heber, C. A. Diehl and T. L. Lim. 2000. Ammonia, Hydrogen Sulfide and Carbon Dioxide Release From Pig Manure in Under-Floor Deep Pits. J. Agric. Engr. Res. 77(1):53-66.
O'Neill, D. H. and V. R. Phillips. 1992. A Review of the Control of Odour Nuisance from Livestock Buildings: Part 3, Properties of the Odorous Substances Which Have Been Identified in Livestock Wastes or in the Air Around Them. J. Agric. Engr. Res. 53: 23-50.
Ouwerkerk, D., and A. V. Klieve. 2001. Bacterial diversity within feedlot manure. Anaerobe 7:59-66.
Parbst, K. E., K. M. Keener, A. J. Heber and J. Q. Ni. 2000. Comparison Between Low-End Discrete and High-End Continuous Measurements of Air Quality in Swine Buildings. Applied Engineering in Agriculture. Volume 16(6):693-699
Schiffman, S. S., B. W. Auvermann and R. W. Bottcher. 2001. Health Effects of Aerial Emissions From Animal Production Waste Management Systems. Report to Proc. Int'l Symp. An. Production and Env. Issues. Research Triangle Park, NC.
Spoelstra, S.F. 1980. Origin of Objectionable Odorous Components in Piggery Wastes and the Possibility of Applying Indicator Components for Studying Odour Development. Agriculture and Environment. Volume 5 (1980) 241-260.
Tengman, C. L., R. N. Goodwin and J. R. Bicudo. 2001. Hydrogen Sulfide Concentrations Around Swine Farms. Proc. Int'l. Symp. An. Production and Env. Issues. Research Triangle Park, NC. October 3-5, 2001.
Widdel, F. 1988. Microbiology and ecology of sulfate- and sulfur-reducing bacteria. In: A. Zehnder (ed.) Biology of Anaerobic Microorganisms. pp. 469-585. John Wiley & Sons. New York, NY.
Williams, A.G. 1984. Indicators of Piggery Slurry Odour Offensiveness. Agricultural Wastes 10 (1984) 15-36
Winegar, E. D. and C. E. Schmidt. 1988. Analyzing using a Jerome 631-X portable hydrogen sulfide sensor: Laboratory and field evaluation. Report to Arizona Instruments, Corp. Applied Measurement Science. Fair Oaks, CA.
Wood, S. L., K. A. Janni, C. L. Clanton, D. R. Schmidt, L. D. Jacobson and S. Weisberg. 2001. Odor and Air Emissions from Animal Production Systems. ASAE Meeting Presentation Paper No. 014043.
Zahn, J. A., J. L. Hatfield, D. A. Laird, T. T. Hart, Y. S. Do and A. A. Dispirito. 2001b. Functional Classification of Swine Manure Management Systems Based on Effluent and Gas Emission Characteristics. J. Environ. Qual. 30:635-647.
Zhu, J., L. Jacobson, D. Schmidt and R. Nicolai. 2000. Daily Variations in Odor and Gas Emissions from Animal Facilities. Applied Engineering in Agriculture. Vol. 16(2) 153-158.