Best Technologies for Reducing Odor Emissions from Curtain-Sided, Deep Pit Swine Finishing Buildings

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Executive Summary

A three year research project was funded by the Minnesota Pork Producers Association to address the problems of odors, noxious gases and greenhouse gases produced in the popular deep pit curtain sided building. Several technologies were evaluated in pilot scale testing or laboratory testing while others were installed and monitored long term on full scale production facilities.

BIOFILTRATION

Odor and hydrogen sulfide emission reduction of 70% - 95% were measured from a biofilter placed on a curtain pig finishing barn when the curtains were closed (during mechanical ventilation). During natural ventilation or when the curtains were open, odor and gas reduction decreased to 5% - 50%. Ammonia emission reduction was very variable.

OIL SPRINKLING

The daily sprinkling of soybean oil inside a pig finishing curtain-sided barn using an existing “soaker” distribution system reduced the indoor concentration of NH_3, H_2S, and odor by roughly 30%, 20%, and 10% respectively. This technology did provide moderate to high reductions (60 to 80 %) in total dust levels inside the building. Future work with different nozzles that do not clog with the oil and water mixture is needed as well as improving the distribution of the oil-water sprinkling.

OZONE AIR TREATMENT

Ozone was added to a full scale finishing barn. Ozone air treatment reduced odors 25% as compared to the control barn during the cold months when the building had much less ventilation and the curtains were not open. During warm months when the curtains were providing most of the ventilation, no odor reduction was seen. The hydrogen sulfide situation was similar in that there was an improvement during the colder months (33% reduction) but not during the warmer months. Ammonia during the colder months was essentially the same and better in the control barn during the warmer months. Dust levels were reduced in the ozone treated barns. There is anecdotal evidence of improved pig health in the ozone barn.

CHEMICAL ADDITION DURING PUMPOUT

Hydrogen peroxide was added to finishing barn pits during agitation and pumping. Data suggest a 67% reduction in hydrogen sulfide concentrations between treatment and control. Laboratory studies showed as much as 90% reduction.

DIET FORMULATION

The use of Standardized ideal digestibility (SID) formulation and adding synthetic amino acids had no effect on energy and nitrogen digestibility and excretion. However, feeding the SID diet reduced slurry pH, ammonia emissions and tended to reduce hydrogen sulfide emissions during weeks 13-15 of the study. Although it appears that some benefit was obtained for reducing gas emissions, feeding the SID diet had no effects on manure odor detection, intensity or hedonic tone.

NON THERMAL PLASMA

A prototype nonthermal plasma reactor with wire-to-plate geometry was designed to utilize highly effective structural parameters to achieve the desired pollutant removal efficiency. Removal efficiencies of 97% were obtained from hydrogen sulfide at a flow rate of 5.7 m^3/min using 10 kV applied voltage generated by 110 V 60 Hz power supply. The dilute gases normally exiting a biological reaction of stored manure were reduced by 95% with some residual ozone in the air stream.

EVALUATION OF TECHNOLOGIES

The financial and management aspects of new technologies are important in acceptance of technologies by producers. An Excel spreadsheet was developed to assess the cost effectiveness of several odor control technologies. The variable costs of operating technologies ranged from a few cents per marketed pig to $1 per pig. The most difficult item to measure is the benefit from the technologies to an individual operator. Lost opportunity due to blocked expansion, community stress from challenges to production and management costs to process legal papers and deal with environmental challenges are considerations that may affect acceptance of technology to satisfy local challenges.

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Introduction

Odors and specific gases, like hydrogen sulfide and ammonia, generated from pig production units are a major concern for individual pork producers, state and local regulators, the general public, and the Minnesota pork industry. One source of these emissions that has been overlooked by most control technologies and other research is the deep-pitted, curtain style-finishing barn. Deep-pitted curtain barns are by far the most common housing system for finishing pigs used by producers in Minnesota and the upper Midwest. Currently, most of the 9.2 million slaughter pigs produced in Minnesota per year are grown in these types of facilities. These buildings are economical and generally believed to be environmentally sound. Emissions of gases and odors from these buildings (or the emissions potential for proposed units) have prompted the state's regulatory agency, Minnesota Pollution Control Agency (MPCA), to require producers to implement some type of odor/gas control technology on their facilities. This puts the pork producer in a difficult situation with comparative economic disadvantage to other states. First, in selecting a technology that is effective for Minnesota weather conditions and secondly, verifying if the technology selected reduces the gas/odor emission levels sufficiently to satisfy the MPCA and local officials and neighbors. Thus, there is a need to evaluate several odor/gas reduction technologies, which can be adapted to this type of housing system within the economic and labor constraints of the average producer.

The evaluation of several gas/odor reduction technologies for deep-pitted curtain style finishing barns provides Minnesota pork producers with valuable information on the practical control of these emissions. Not only does this benefit individuals who are facing immediate stipulations in their permits, but also provides options for existing operations that they may want to use to reduce total emissions from their sites either to accommodate neighbors' concerns or to allow for expansion at an existing site. In short, it may allow for continued growth of the industry in the state, at least at finishing stage of production.

Objective

The objective of this research was to develop a list of effective and reasonable odor reducing and nutrient management systems for deep pit curtain-sided swine barns in Minnesota. These systems will give the producers viable and understandable choices that they may use to meet environmental, regulatory, and economic pressures in the next five years. Issues to be addressed include emissions of odors, hydrogen sulfide, ammonia, and global warming gases.

Procedures to Achieve Objective

The team of researchers assembled a list of the known systems and technologies that are deemed applicable to Minnesota conditions and the deep pit barns.

A quantitative analysis was completed using Microsoft Excel computer spreadsheet template. The spreadsheet had two components:

1. A partial budget model of the required investment, annualized ownership costs, and annual operating costs for each technology considered. A preliminary list was eventually

narrowed to six technologies that were tested (oil sprinkling, ozone treatment of inside air, biofilters and adding hydrogen peroxide to the manure pit, straw wall, frequent pumping of pit).

2. A summary table containing a row for each alternative and a number of columns, with a column for each economic measure of interest (operating cost/cwt. of pork produced, total cost/cwt. of pork, etc.)

The procedure for the economic analysis was that all of the researchers familiarized themselves with the budget model. Once they all understood the data requirements and relationships in the model, met for several brainstorming sessions to identify:

a) The set of attributes that form the basis for the comparison,
b) Where that attributes enters into the budget model, and
c) A value for that attributes for each alternative technology or system.

Between the sessions, a research associate built linkages between the attributes and the model and conducted trial runs, while the researchers refined the attribute values. The team identified meager or lacking information on the most promising systems. To obtain this information, five pilot-test systems were placed on cooperating farms to determine effectiveness of those technologies. Data (ammonia, hydrogen sulfide, strength of odor, operational costs, capital costs) were taken to improve input into the economic models. Paired buildings, treatment and controls, were used to minimize the effects of location, management differences, and storage conditions. The researchers most knowledgeable in each technology provided the specific leadership for installing these technologies on location. The team continued testing the three most promising systems on farms. Control buildings were used to determine if the technologies significantly affect the odors and regulated gases produced. For these three systems, the team leveraged funding to get the full sized systems installed to obtain reliable data on these field systems.

Odor, economic, management, and gas data were analyzed to develop recommendations for producers.

Technologies/systems that were included in the initial evaluation matrix:

Mechanical separation of solids
Biological separation of solids
Natural separation of solids
Aeration treatment of total storage volume
Aeration of the top part of storage volume
Controlled anaerobic treatment of storage under building
Controlled anaerobic treatment of manure outside of building
Non-thermal plasma treatment of ventilation air
Biofilters added to barns
Partial slats in barns
Covers under slats
More frequent hauling of manure
Chemical additions during agitation

Bedding addition to buildings
Oil treatment of buildings
Windbreaks
Landscaping of sites
Washing walls
Summer injection of manure
Rotation of crops for more frequent manure spreading
Reduction of water usage
Diet manipulation

The initial technologies applied to barns after the subjective decision making process:

Chemical additions during agitation
Ozone treatment of air in building
Biofilters added to barns
Oil treatment of buildings
More frequent hauling of manure
Straw wall near building

Some technologies were continued in pilot situations, not on farms

Diet manipulation
Non-thermal treatment of ventilation air

The final long-term farm sites had the following technologies:

Oil treatment of buildings
Biofilters added to barns (modifications to fans to increase capacity)
Ozone treatment of air in building

Three Long-Term Technologies Evaluated

Odor and gas emission data has been collected from deep-pitted, curtain-sided pig finishing buildings by the investigators, thus measurement techniques and a database have been established (Jacobson et al., 1999). Oil sprinkling inside of a building to reduce dust levels and gas/odor emissions showed mostly positive results in a pig nursery (Jacobson et al., 1998). Other research (Zhang, 1996) would suggest that this technique would work better in a finishing barn environment than in a nursery because of the presence of larger quantities of dust. Biofilters have been researched by University of Minnesota's Biosystems and Agricultural Engineering Department and have shown a significant reduction in gas and odor reduction from fan (only) ventilated buildings (Nicolai and Janni, 1998). Ozone Treatment of the air inside a curtain-sided barn was evaluated by Goodrich et al. (2000).

Oil Sprinkling-- Leader: Larry Jacobson

Subobjective: To determine if spraying an oil/water mix in the pens would reduce odor and gas emissions from the barn.

An oil sprinkling system was developed for Minnesota style curtain-sided pig finishing barns that use the existing water “soaker” distribution systems that many facilities have installed in their units to aid cleanup between pig groups. The system consists of a small liquid (oil) injection pump, solenoid valve, and timers (Figure 1) plus plumbing supplies to convert the existing soaker distribution systems into an oil sprinkling distribution system. These modifications were made to two commercial 1000 head pig finishing rooms that had adjacent 1000 head finishing rooms that became experimental controls. Approximately 1.5 gallons of vegetable (soybean) oil (stored in a 55 gallon barrel) were sprinkled once a day (Figures 2 and 3) over a 1-minute time period in the treatment rooms.

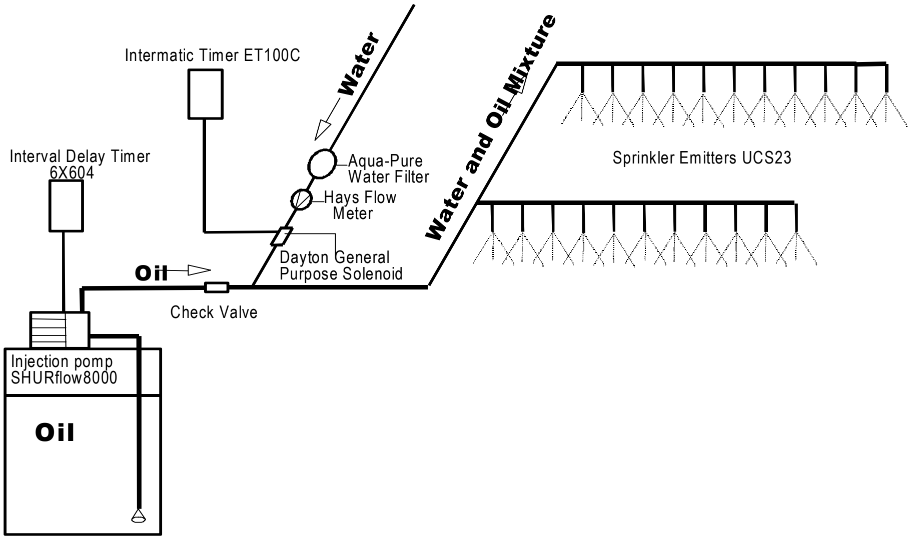

Figure 1. Schematic of oil sprinkling system

Figure 2. Injection oil pump and storage barrel plus plumbing for oil sprinkling system.

Figure 3. Spinner nozzle distributing oil-water mixture in finishing barn.

The capital cost of the equipment for the sprinkling system is about $320 with Table 1 listing the specific components. This cost does not include the cost of sprinklers and plumbing since these are already in many existing barns. The operating cost for this system includes the cost of the oil and surfactant. Three gallons of surfactant were added to a 55-gallon oil drum to satisfy the 5% solution ratio recommendations, increasing the cost of oil to roughly $4.00/ gallon. About 1.3

gallons of oil/surfactant solution was sprayed every day in this project, which results in an approximate operating cost of $5.20 per day. Assuming the facility operates 350 days/year, this would result in an operating and maintenance cost of around $2000 per year. With a five-year useful life and an interest rate of 6% this is approximately $2.13 per pig place per year for a 1000 head building.

Table 1. Oil sprinkling system cost

	Components	Cost ($)
1	Injection pump SHURflo8000 model 4UN55	$104.00
2	Intermatic timer ET100C	$57.00
3	Dayton interval delay timer 6X604	$60.00
4	Dayton general purpose solenoid	$95.50
	Initial cost	***$316.50***
5	Surfactant Alkamuls 600-DO (Rhodia Inc.)	$17.50 /gal
6	Soybean oil (Hi Energy Golden Liquid, OCCO Products)	$ 3.30 /gal

Odor, gas, and dust concentrations and emissions results (Paszek, 2001) from the first farm are not presented in this report due to inconsistent results caused by numerous mechanical problems with the oil sprinkling system and difficulty in measuring true exhaust air from the treatment and control rooms during warm weather conditions. The percent reduction for the average odor, NH_3 and H_2S, concentrations of the oil sprinkling treatment for Farm 2 are presented in Table 2. The reduction percentages vary widely over the nearly one-year time period that data was collected and are low to moderate (10 to 28%) and are statistically significant at the 5% level for hydrogen sulfide and ammonia only (not odor). Although there were days when odor concentrations were reduced from 40 to 60%, the average reduction for all ten dates was 10%.

Percent reduction = (1-treated/control)*100

The reduction in average respirable, inhalable, and total dust concentrations from the oil sprinkling treatment are shown for farm 2 in Table 3. There is more consistency and moderate to high reduction values for the inhalable and total dust parameters (60 and 80% respectively). This was not the case for the respirable fraction that is the very small dust particles that resulted in less than a 10% reduction compared to the control room. This is consistent with previous research and was the main purpose in developing this technology.

Table 2. Percentage reduction for average H_2S, NH_3 and odor concentrations of Oil Sprinkling

	H2S (ppb)		NH3 (ppm)		Detection OU		% reduct.	% reduct.	% reduct.
Collection Date	Oil	Control	Oil	Control	Oil	Control	H2S	NH3	OU
8/1/2000	32.5	21.5	1.60	1.08	111	81.8	-51.2	-47.9	-35.6
8/15/2000	34.5	38.50	1.39	1.51	73.3	170	10.4	7.85	56.9
9/13/2000	75.0	139	1.17	3.88	82.3	141	46.1	69.9	41.5
9/27/2000	87.3	195	3.03	5.75	114	182	55.3	47.3	37.2
11/29/2000	585	610	8.00	12.9	506	337	4.10	37.7	-50.1
12/13/2000	1500	1600	9.00	16.5	610	572	6.25	45.5	-6.70
2/22/2001	410	497	9.33	10.7	548	624	17.4	12.5	12.1
3/6/2001	280	383	4.67	8.67	574	953	27.0	46.2	39.8
4/25/2001	79.7	97.7	1.30	1.70	302	276	18.4	23.5	-9.67
6/6/2001	186	339	4.23	6.55	498	621	45.2	35.5	19.7
Average	**327**	**392**	**4.37**	**6.92**	**342**	**396**	**17.9**	**27.8**	**10.5**
						STDEV	***30.1***	***32.2***	***35.4***
						t	***1.88***	***2.73***	***0.94***
						TINV	***1.83***	***1.83***	***1.83***
						p-value	***0.046***	***0.012***	***0.186***

Table 3. Percentage reduction for average respirable, inhalable and total dust concentrations in oil sprinkled rooms.

	Respirable dust conc. (mg/m^3)		%	Inhalable dust conc. (mg/m^3)		%	Total dust conc. (mg/m^3)		%
Collection Date	Oil	Control	reduction	Oil	Control	reduction	Oil	Control	reduction
2/20/2001	0.138	0.214	35.5	1.10	6.51	83.2	1.55	5.00	69.1
3/6/2001	0.035	0.726	95.2	1.90	4.82	60.5	2.60	4.96	47.5
5/9/2001	0.044	0.029	-51.7	0.04	0.37	90.3	0.23	0.57	59.9
6/6/2001	0.055	0.037	-48.6	0.16	0.84	81.4	0.52		
		Average	***7.6***		***Average***	***78.8***		***Average***	***58.8***

Summary for soybean oil sprinkling

The daily sprinkling of soybean oil inside a pig finishing curtain-sided barn using an existing "soaker" distribution system reduced the indoor concentration of NH_3, H_2S, and odor by roughly 30%, 20%, and 10% respectively. This technology did provide moderate to high reductions (60 to 80 %) in total dust levels inside the building. Future work with different sizes and or types of nozzles that do not clog with the oil and water mixture is needed as well as improving the distribution of the oil-water sprinkling. An odor control factor of 0.8 (20% odor reduction) will be used for the oil sprinkling technology in the OFFSET (Odor From Feedlots – Setback Estimation Tool) model.

Biofilters--Leader: Richard Nicolai

Subobjective: To determine if a biological filter would reduce the odors and gases exiting the barn.

A 40 ft. x 21 ft. biofilter was constructed in October 1999 to treat the exhaust air from pit ventilation fans on the west half of a 41 ft. x 200 ft. curtain-sided pig finishing barn (1000 head total capacity). The existing pit ventilation fans were replaced with fans (four Multifan model 2E35 fans) that could operate at a higher static pressure created by the biofilter and deliver the same airflow (8000 cfm). A second biofilter was constructed on the east half of the same swine finishing barn in November 2000. Its purpose was to determine if preventing pit gases from being exhausted through the curtain area could increase the overall emissions reduction. The pit fan system for the east room was modified to exhaust 15,500 cfm at 0.4 inches of water static pressure by replacing the original fans with two Raydot model PBF18G60S41 and two Raydot model PBF24G50S41 fans. To treat 15,500 cfm, the biofilter size was increased to 60 ft. x 28 ft. Both biofilters were 1 ft. deep and had an empty bed contact or residence time of 5 seconds.

Figure 4. Biofilter built on a curtain-sided pig finishing barn (west half) with curtain closed

The investment cost for a biofilter on a 1000 head barn is estimated at $8000 which includes the costs of the pallets, media, fan upgrade (replace 1/3 hp fans with 1/2 hp fans), duct materials, water sprinkler system, and labor. The spreadsheet has a listing of specific components. The biofilter is assumed to last the life of the buildings (20 yrs) but the media and some pallets would need to be replaced every 5 years. Operating and maintenance expenses would consist of extra electricity by the larger hp fans, weed, moisture and rodent control, and labor for maintenance and media and pallet replacement that would result in an estimated $1,500 per year cost. This calculates out to $2.44 per pig place per year cost for a 1000 head barn assuming an interest rate of 6%.

Odor, H_2S, and NH_3 emissions results from each half of the biofilter on the pig finishing barn were calculated from the measured concentration and airflow. Total emission without the biofilter included the emission from the pit fans and from the curtain area. Total emission with the biofilter included the emission from the biofilter exhaust and curtain area. Reduction percentage was determined by:

Percent Reduction = (1-biofiltered air/unfiltered air)*100

Figure 5 shows the odor emissions reduction for both biofilters. During the winter months when the curtains are closed, odor emission reduction is greater then 70%. When the curtains were opened the west biofilter odor reductions varied between 3% and 50%. The variation can be explained by ambient wind velocity. The reduction through the biofilter remained constant, but as the wind velocity increased the natural ventilation airflow and thus emissions through the curtain openings resulted in less total odor emission reduction.

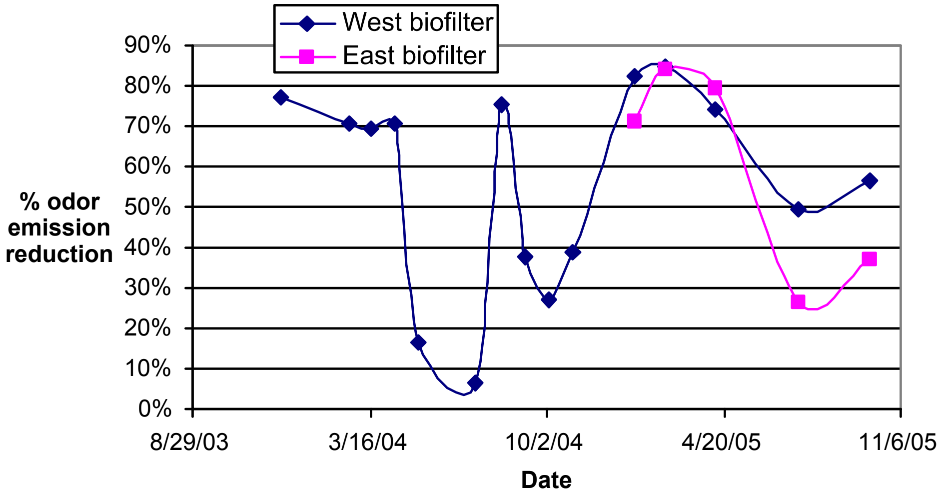

Figure 5. Odor emission reduction from a curtain-sided pig finishing barn using a biofilter.

The odor emission reductions from the east half of the barn were similar to those of the west barn. During the winter months with the curtains closed the reduction exceeded 70%. With the curtains open, odor emission reduction dropped to 23%, which was similar to the west half of the barn.

Hydrogen sulfide emission reductions showed a similar pattern to odor reduction, i.e. reductions greater than 80% when the curtain was closed and 5% to 80% when opened. The reduction in H_2S concentrations through the biofilter ranged from 47% to near 100% with an average of 83%.

Ammonia reductions varied from 0% to 100% for the west biofilter during 2000. Both biofilters followed a similar pattern to odor and hydrogen sulfide during 2001, i.e. higher reductions when the curtain was closed. The cause of this variability has not been determined.

Summary for Biofilters on Pit Fans

Odor and hydrogen sulfide emission reduction of 70% - 95% were measured from a biofilter placed on a curtain pig finishing barn when the curtains were closed (during mechanical ventilation). During natural ventilation or when the curtains were open, odor and gas reduction decreased to 5% - 55%. By increasing the ventilation airflow through the fans and biofilter, the curtain remained closed a longer amount of time. Ammonia emission reduction was very variable. More research is required to explain the variability. The biofilters on these curtain-sided finishing barns were operating less efficiently when compared to other biofilters on swine facilities (Nicolai and Janni, 2000). Hydrogen sulfide concentration reduction averaged 83% compared to 90% - 95% and odor reduction averaged 77% compared to 85% to 95%. Lack of water sprinkling on the biofilter surface during the summer may explain the difference. A range of odor control factors, 0.8 to 0.5 (20 to 50 % odor reductions) will be used for biofilters in the

OFFSET model on curtain-sided barns depending on the percentage of airflow that is passed through the filtering media.

Ozone Treatment of Air--Leader: Philip Goodrich

Subobjective: To determine if ozone injected into the air space of the barn reduced gases and odors exiting the barn.

An existing two-year old curtain-sided barn was located which had an ozone treatment system installed in one-half of the barn. The two halves of the barn were separated by a workroom, but were operated in the same way so that one could be used as a control. The 2000 pigs were from the same source and were placed in the two halves at the same time. Barrows were on the south side of both halves and gilts were on the north side. Air samples were collected at the pit exhaust fans into10 liter Tedlar™ bags using a vacuum box. Hydrogen sulfide was analyzed using the Jerome meter, ammonia using calorimetric tubes from Sensedine, and odor threshold was measured in the laboratory using dynamic forced choice olfactometer as described by Nicolai (1999). Dust was collected in the center of the building using gravimetric methods for total dust and inhalable dust .

The ozone generator was an AGRI-Air OM-20 producing up to 20 grams per hour of ozone into 220 CFM duct fans, which distributed the mixture of ozone and air down the length of the barn in two ducts. This ozone generator used a 30 kilovolt DC corona discharge generator and consumed 900 watts according to literature. At that consumption and energy cost of $0.07 per kilowatt-hour, the energy cost per month was about $45. Installed cost of the system was approximately $10000 to serve one barn.

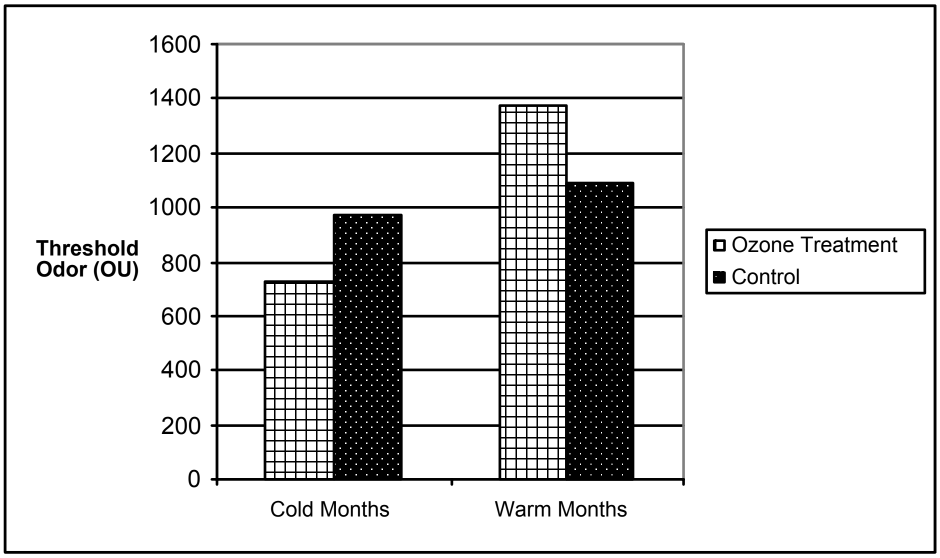

Figure 6. Threshold odor values for cold and warm months measured at pit fans.

From figure 6 it is observed that the ozone treatment was beneficial in reducing odors during the cold months when the building had much less ventilation and the curtains were not open. But during the period when the curtains were providing most of the ventilation, the odors were better in the non ozone building. The hydrogen sulfide situation was similar in that there was an improvement during the colder months but not during the warmer months as shown in figure 7.

The ammonia during the colder months was essentially the same and better in the control barn during the warmer months. From this one might conclude that there was some benefit when the curtains were up and no benefit when the buildings were more open in the warmer months.

The dust levels measured were better in the ozone treated barn compared with the control barn. The decreased dust levels may have been from the small "ion device" that was a part of the installed ozone system.

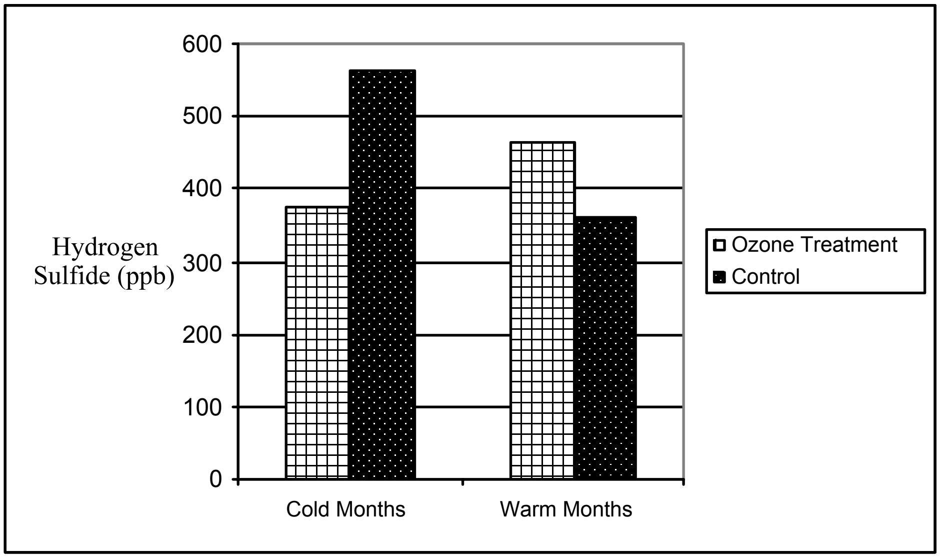

Figure 7. Hydrogen sulfide values for cold and warm months measured at pit fans.

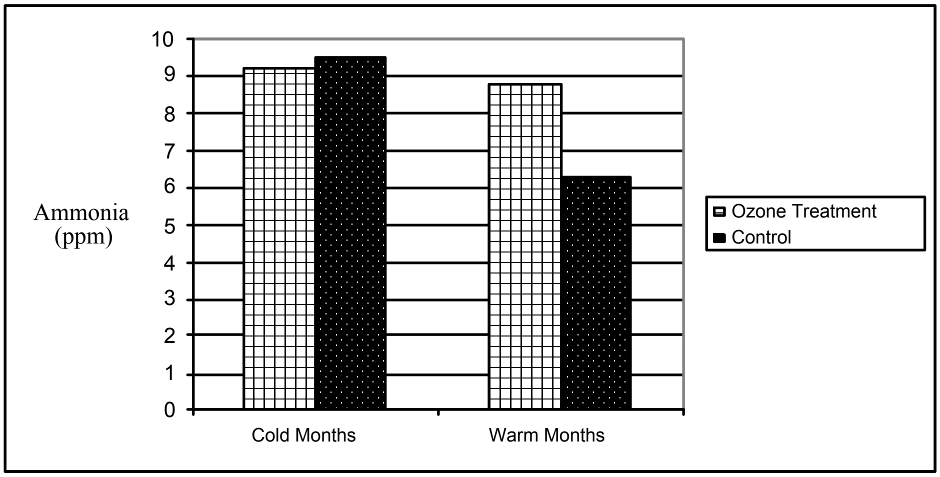

Figure 8. Ammonia values for cold and warm months measured at pit fans.

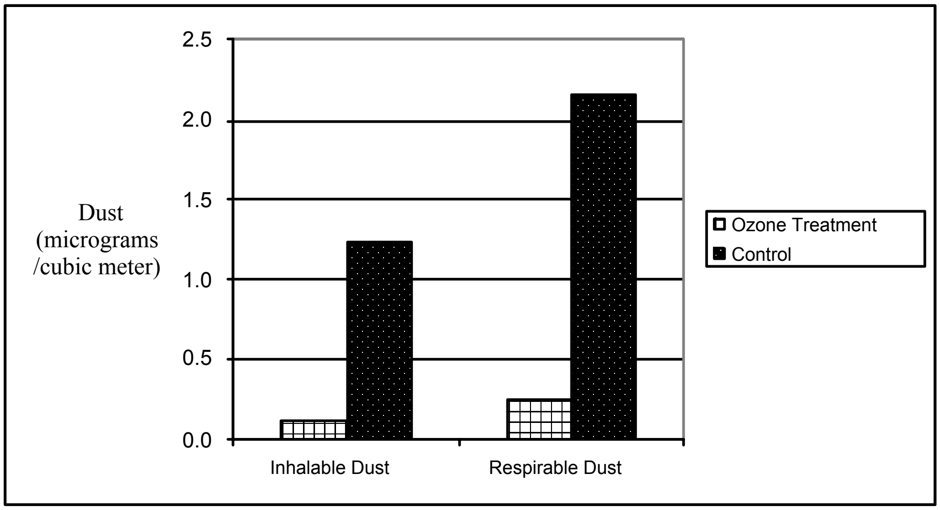

Figure 9. Dust measured in the building.

Summary for Ozone Treatment

The ozone treatment was beneficial in reducing odors during the cold months when the building had much less ventilation and the curtains were not open. But during the period when the curtains were providing most of the ventilation, the odors were better in the non ozone building. The hydrogen sulfide situation was similar in that there was an improvement during the colder months but not during the warmer months.

The ammonia during the colder months was essentially the same and better in the control barn during the warmer months. There was some benefit when the curtains were up and no benefit when the buildings were more open in the warmer months.

The operator of the building provided information for three groups of pigs. The operator reported death loss in the treated barn (1.0%) was less than (1.5%) in the control barn. The medications administered in the control barn (100 per day) were much more than in the treated barn (50 per day). So the operator had improved performance based on the animal evaluation.

Short Term Investigations on Farms

Chemical Addition for Hydrogen Sulfide Control--Leader: Charles Clanton

Subobjectives: The objective of this research is to evaluate the effectiveness of chemical additions in reducing hydrogen sulfide (H_2S) gas emissions during agitation and pumping swine manure. The goal is to identify a specific chemical and dosage rate.

Swine Manure Bench Top Study

Seven chemicals were initially identified as reducing H_2S emission for a bench top experiment:

- Calcium hydroxide (lime) ($Ca(OH)_2$)
- Ferric chloride ($FeCl_3$)
- Ferrous chloride ($FeCl_2$)
- Ferrous sulfate ($FeSO_4$)
- Hydrogen peroxide (H_2O_2)
- Potassium permanganate ($KMnO_4$)
- Sodium chlorite ($NaClO_2$)

Dosage curves were developed for each chemical to reduce H_2S emission from 20% up to 90%. From these seven curves, the amount of chemical needed and costs to reduce 50% of the emissions was determined (Table 4). Hydrogen peroxide and potassium permanganate appeared to be the most cost-effective. If aglime (at a dose that reduced emissions by 50%) could be purchased and delivered to the site for $10 per ton and added to the pit, the costs would be approximately $0.014/m^3 ($3.00/1000 gallons) of manure.

Table 4. Costs analysis for chemicals.

	Quantity	Costs[1] Dollars/lb.	Amount[2] g/m^3	Cost[3] Dollars/ m^3
Calcium hydroxide ($Ca(OH)_2$)	50 lb. bags	0.374	622	0.51
Ferric chloride ($FeCl_3$)	643 lb. drum, 40%	0.69	6260	23.81
Ferrous chloride ($FeCl_2$)	577 lb drum, 28%	0.55	238	1.03
Ferrous sulfate ($FeSO_4$)	55 Gal Drum, 28%	0.60	221	1.04
Hydrogen peroxide (H_2O_2)	490 lb NR drum	1.09	30.7	0.074
Potassium permanganate ($KMnO_4$)	330 lb NR drum	1.81	15.5	0.062
Sodium chlorite ($NaClO_2$)	100 lb NR drum	3.90	150	1.29

1/ Obtained from Hawkins Chemical, Inc., Minneapolis, MN, June 29, 1999.

2/ Amount needed for 50% reduction in H_2S emission expressed as g of chemical per m^3 of manure. Assumes total solids content of 1.6%.

3/ Dollars per m^3 of manure.

Swine Manure Columns

Based on the swine manure bench-top study of seven chemicals and the economics of purchasing the seven chemicals, hydrogen peroxide (H_2O_2) and potassium permanganate ($KMnO_4$) was chosen to be further tested in manure filled columns. Forty PVC columns were loaded with swine manure on a weekly basis. The total solids content of each pipe was determined. Agitation of columns was done by a modified paint stirrer. Testing H_2S emissions from the columns used the following experimental setup:

- Two chemical application methods
    - Applied at the same time as agitation starts (or a few sec before)
    - Applied 6 min before agitation starts
- Five reduction targets
    - 0%, 30%, 50%, 70%, 90%
- Four collection days
    - Dec. 21 – H_2O_2, Replicate 1, 10 columns
- Dec. 22 – $KMnO_4$, Replicate 1, 10 columns
    - Dec. 28 – H_2O_2, Replicate 2, 10 columns
    - Dec. 29 – $KMnO_4$, Replicate 2, 10 columns
- Jerome meter readings
    - Readings were collected every 30 sec for H_2S concentration
    - Time zero is start of agitation
- Total collection time of 20 min per column
- Tedlar bag as backup with composition air sample
    - Collect one 10-L during first 10 min
    - Second 10-L during second 10 min

Results indicate that there was no statistical difference in H_2S concentration after time zero (when agitation starts) whether the air sampling was started at time zero or 6 min before time zero, thus the data was pooled over these two events. This resulted in four replications instead of two.

Results of the column is located in Table 5, which is the mean H_2S concentration in the collected air samples for the time period 10 to 20 min following the chemical addition. For $KMnO_4$, the concentrations decreased as planned. But for the H_2O_2, there was no statistical difference between the 30% through 90% reduction. This indicates that the original bench-top dosage curves for H_2O_2 maybe in error.

Table 5. Hydrogen sulfide concentration in air samples collected above swine manure in column testing using hydrogen peroxide and potassium permanganate chemical addition. Concentrations are means for the 10 to 20 minute period following chemical addition.

	Targeted Reduction	Chemical Added g / kg DM	Mean Hydrogen Sulfide Concentration, ppm
Hydrogen Peroxide, 50%			
	Control	0	4.13 A
	30%	3.4	0.194 B
	50%	12.8	0.250 B
	70%	27.0	0.233 B
	90%	57.5	0.188 B
Potassium Permanganate			
	Control	0	4.10 A
	30%	0.69	3.50 B
	50%	1.37	1.73 C
	70%	2.41	0.942 D
	90%	4.65	0.620 D

Within each chemical, means with the same letter designator are not significantly different at the $p < 0.05$ level per Duncan's Multiple Range Test.

Initial Swine Manure Field Trial

During spring of 2000, a field trial using hydrogen peroxide was conducted at a cooperating pork producer's facility. This facility contained two identical 41 x 200 ft deep-pitted barns, separated by approximately 75 ft. Each barn was collecting manure from 1000 finishing pigs. One barn was chosen as the control (no chemical) barn and the other served as the treated barn. Within each barn, a concrete wall separated the deep pit into two compartments. Based on our laboratory testing, a single treatment of 110 gal of 30% H_2O_2 was used, with the goal of achieving a 70% reduction in H_2S emissions. The total treatment cost was $1,100 or approximately a dollar per pig.

For the first compartment, half the total volume of H_2O_2 was poured into the pump-out pit and allowed to mix into the manure during the agitation process. H_2S concentrations were 240 ppm 30 min after chemical addition, then dropped to 25 ppm after 70 min and then to 3 ppm after 90 min. In the second compartment with the remaining H_2O_2, half of the chemical was evenly distributed on the manure surface by pouring it through the slats, while the other half was poured into the pump-out and agitated into the manure. H_2S concentration peaked at 100 ppm 3 min after start of agitation, then decreased to 28 ppm after 7 min, to 11 ppm after 15 min and to less than 1 ppm after 30 min.

By comparison, H_2S concentration from the control barn (agitated without chemical addition) increased to 250 ppm (maximum concentration the instruments could read) and remained at 250 ppm throughout the two-hour sampling period. Clearly, H_2O_2 reduced H_2S emissions.

Second Swine Manure Field Trial

On October 13, 2000, a second field trial using H_2O_2 was conducted on a cooperating swine producer's facility. Based on the first results, half of the amount was used on October 13; thus a single barrel, 208 L (55 gal) of 30% H_2O_2 was used.

At 8:10 am, 98 L (26 gal) of H_2O_2 was poured through the slats of the east side of the east barn. Figure 10 contains the H_2S concentration of air samples exiting one of the exhaust pit fans. Concentrations of H_2S started to rise about 15 min after the start of pit agitation. The dips in H_2S concentration at about 25, 73, 80, etc. min. are when the agitation pump is switched to transfer mode (temporarily stopping agitation) for filling a tanker. The long high concentration between 35 and 70 min. was due to a mechanical breakdown in the application equipment.

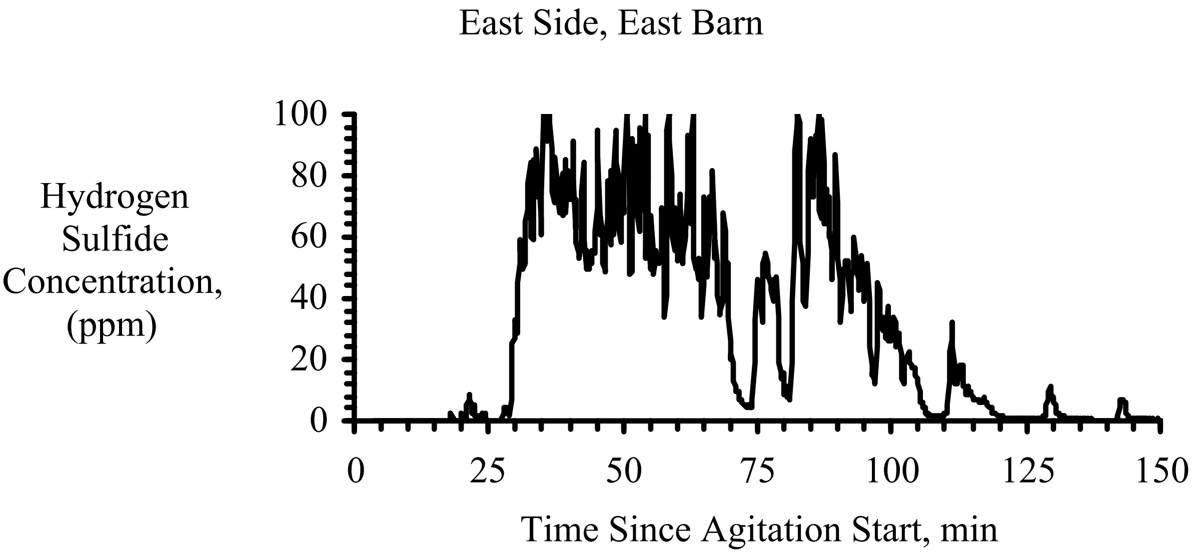

Figure 10. Hydrogen sulfide concentrations at pit exhaust fan Vs time after start of agitation in the east side of the east barn.

At 10:45 am, 98 L (26 gal) of H_2O_2 was poured through the slats of the west side of the east barn. Figure 11 contains the H_2S concentration of air samples exiting one of the exhaust pit fans. As one can see, the concentrations of H_2S concentration emitting from the exhaust pit fan is considerably less. The explanation for this reduction compared to the east side is that manure flows from the west side through the holes to the east side as the east side is pumped. Thus the amount of H_2O_2 added to the east side was underestimated and the amount added to the west side overestimated.

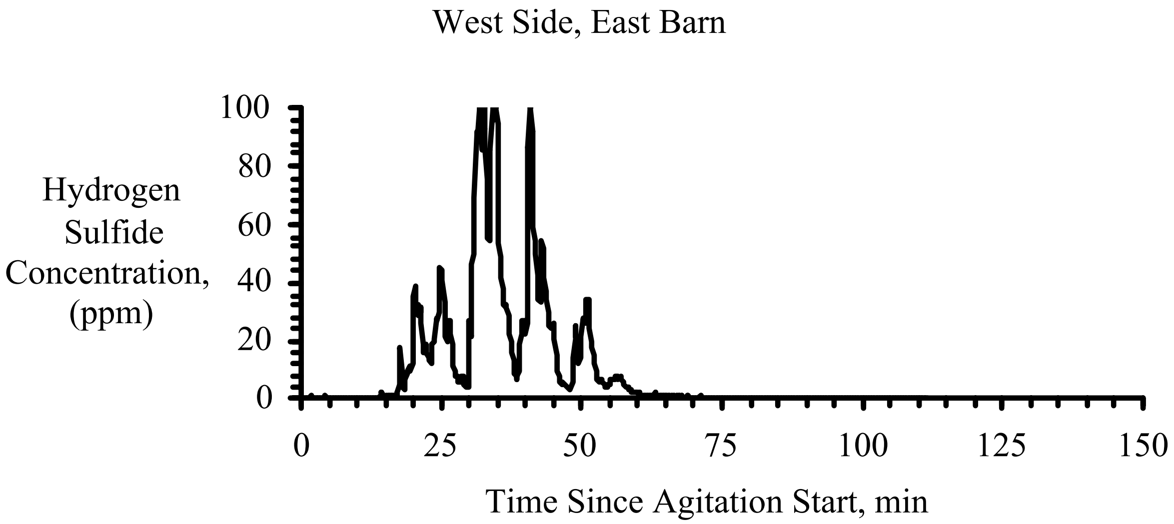

Figure 11. Hydrogen sulfide concentrations at pit exhaust fan Vs time after start of agitation in the west side of the east barn.

Figures 12 and 13 contain air H_2S concentrations from exhaust pit fans of the controls (no chemical addition) collected during the afternoon.

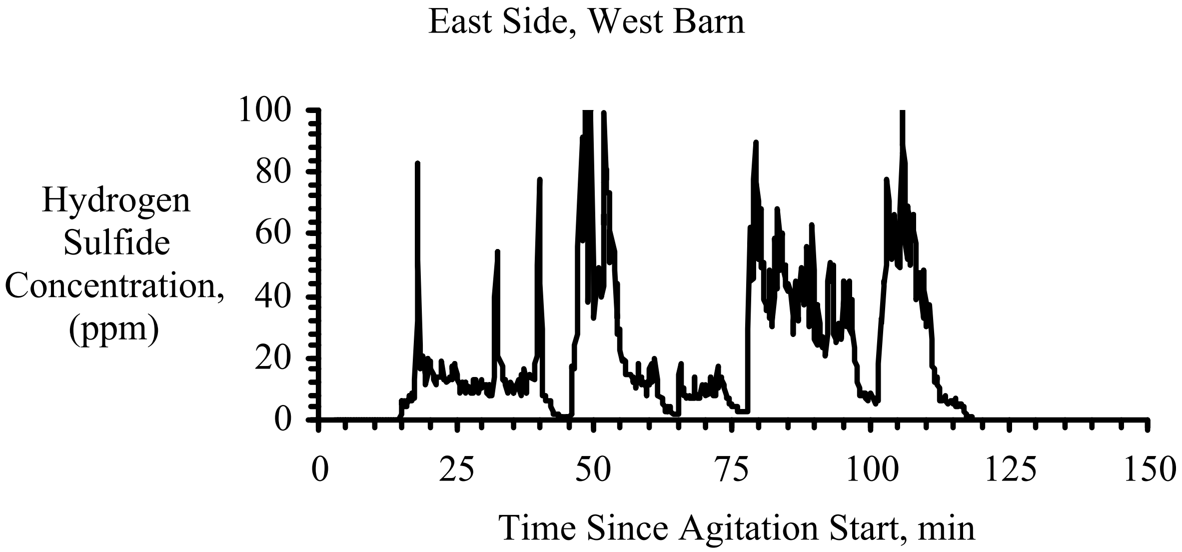

Figure 12. H_2S concentrations from exhaust pit fans of the controls (no chemical addition) collected during the afternoon

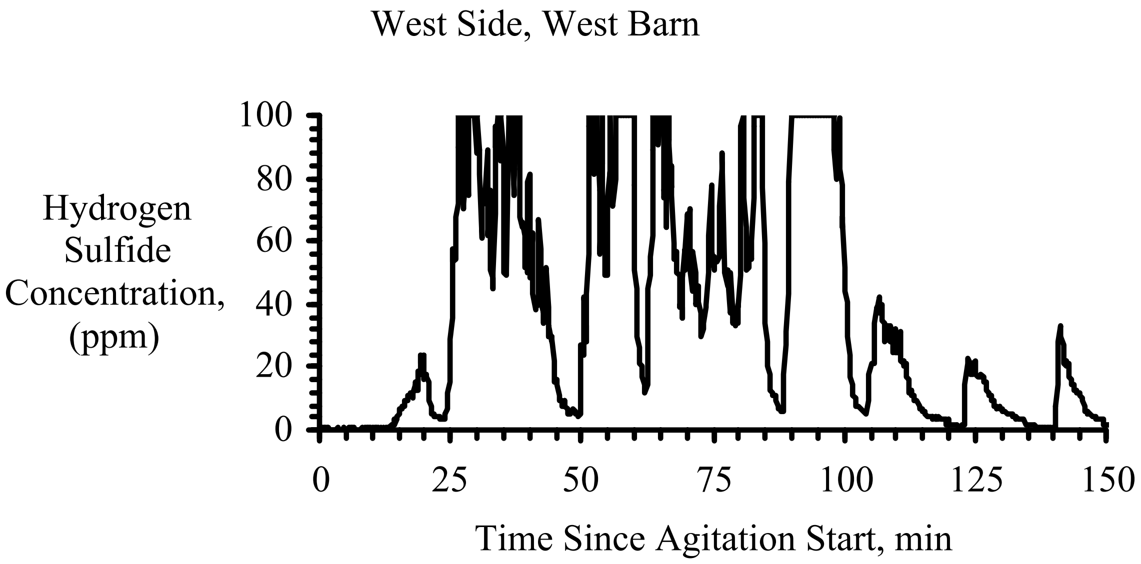

Figure 13. H_2S concentrations from exhaust pit fans of the controls (no chemical addition) collected during the afternoon

In a preliminary comparison of the treated and controls, the area under the curve can estimate the amount of reduction in H_2S emission. The areas are:

Treated		
	East side, east barn	4220 ppm ∗ min
	West side, west barn	1150 ppm ∗ min
	Total	5370 ppm ∗ min
Control		
	East side, west barn	2490 ppm ∗ min
	West side, west barn	5500 ppm ∗ min
	Total	7990 ppm ∗ min

This calculates to a reduction of 33% (7990 – 5370 / 7990) in H_2S concentration averaged over the 150 min. agitation period.

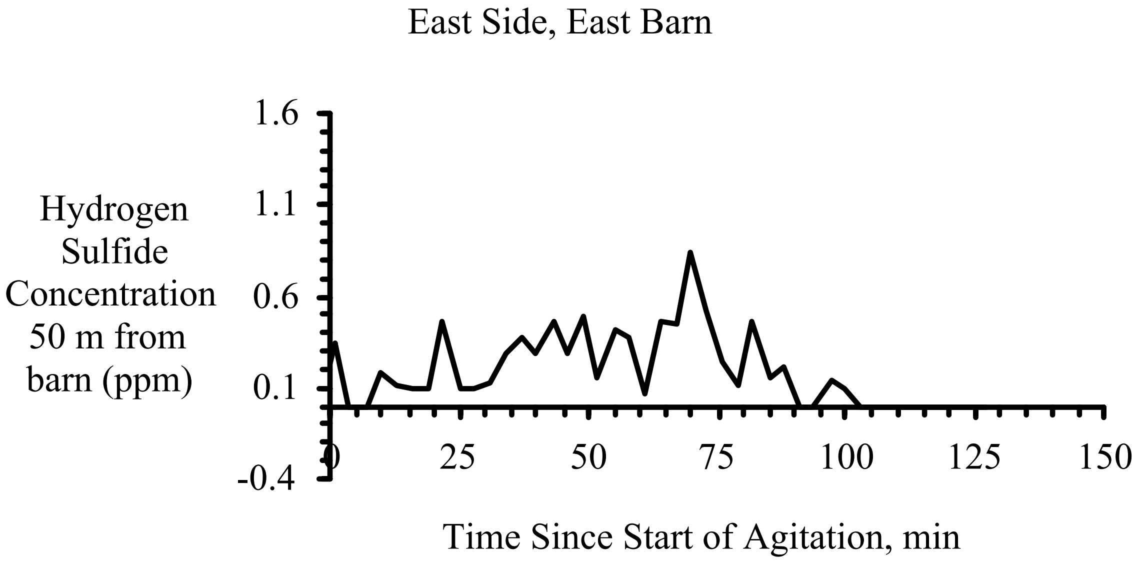

Figure 14. H_2S concentrations 50 meters downwind from the east side of the east barn (treated)

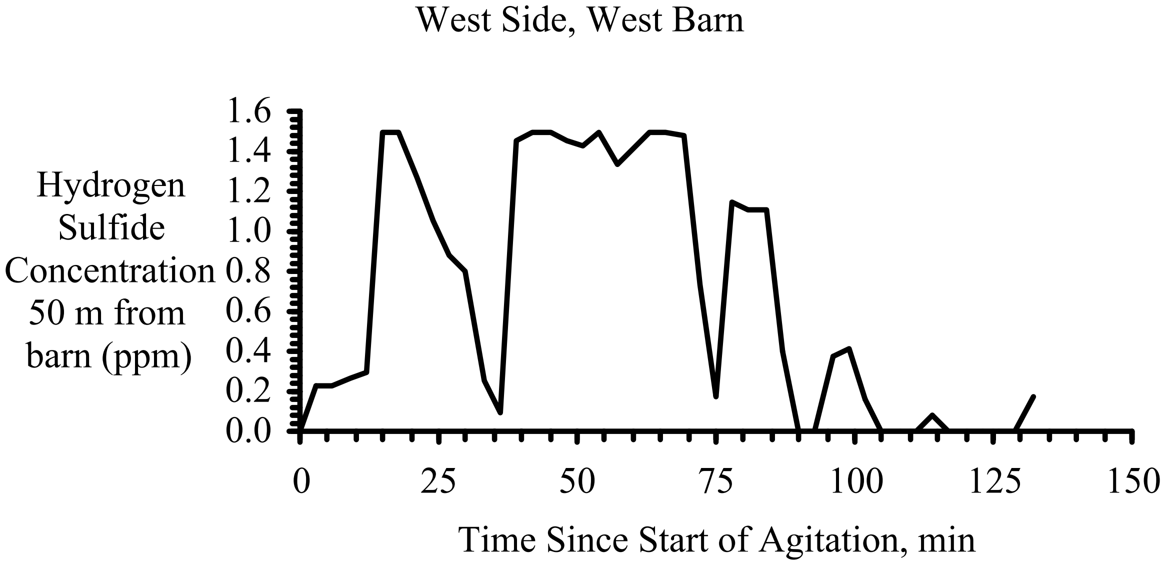

Figure 15. H_2S concentrations 50 meters downwind from the west side of the west barn (control)

Figures 14 to 15 contain the H_2S concentrations in air sample analyzed 50 m (164 ft) downwind from the barns. The fluctuation of these concentrations follows those H_2S concentrations in air collected from the exhaust pit fans (Figures 10-13). In following a preliminary comparison of the treated and controls, the area under the curves are:

Treated	
East side, east barn	25.4 ppm * min
West side, west barn	13.4 ppm * min
Total	38.8 ppm * min
Control	
East side, west barn	28.2 ppm * min
West side, west barn	90.9 ppm * min
Total	119.1 ppm * min

This calculates to a reduction of 67% (119.1 – 38.8 / 119.1) in H_2S concentration averaged over the 150 min. agitation period. However, this reduction calculation may not be as reliable as the calculation from the exhaust pit fans due to the variability in wind speed and direction.

The last thing that might be noteworthy is the ratio of H_2S concentration collected at the two different locations. There was a reduction of approximately 140 (treated barn) and 67 (untreated control barn) fold in the first 50 m (164 ft) from the barn due to dilution with ambient air.

Straw Wall Barrier Situated Near Swine Barn--Leader Larry Jacobson

Project sub objective: *The objective of this research is to evaluate the effectiveness of placing a biological barrier outside the barn to cause mixing and diffusion of the air exiting the barn and as a result reducing the impact of the gases and odors away from the barn.*

A barrier constructed of large round bales was placed 8 meters away and parallel to one barn. Individual trained sniffers (11 persons) were used to determine the strength of the odors (range 0-5) at 25 100 and 200 meters downwind from the barn before and after the wall was placed. Samples were evaluated at 10 second intervals and 60 samples per sniffer were evaluated.

The overall reduction in odor was about 30% with the largest reduction measured at the 200 meter distance.

Logistics were the bane of this project. Managing the 15 people that were needed to do the sniffing as well as selecting weather conditions which allowed sampling in a location 60 miles from campus was very difficult. In addition getting the bales moved to the location and moved to take samples at the correct time proved to be impossible. Therefore only one sample was actually collected although several attempts were made.

There are several drawbacks to the straw wall concept. First is that large bales are usually not available in the areas where most finishing barns are located. The concept of the naturally ventilated building is probably degraded by the straw wall, especially if two walls are installed to disperse the gases and odors in all directions. The straw wall are not aesthetically attractive. They may also become rodent havens.

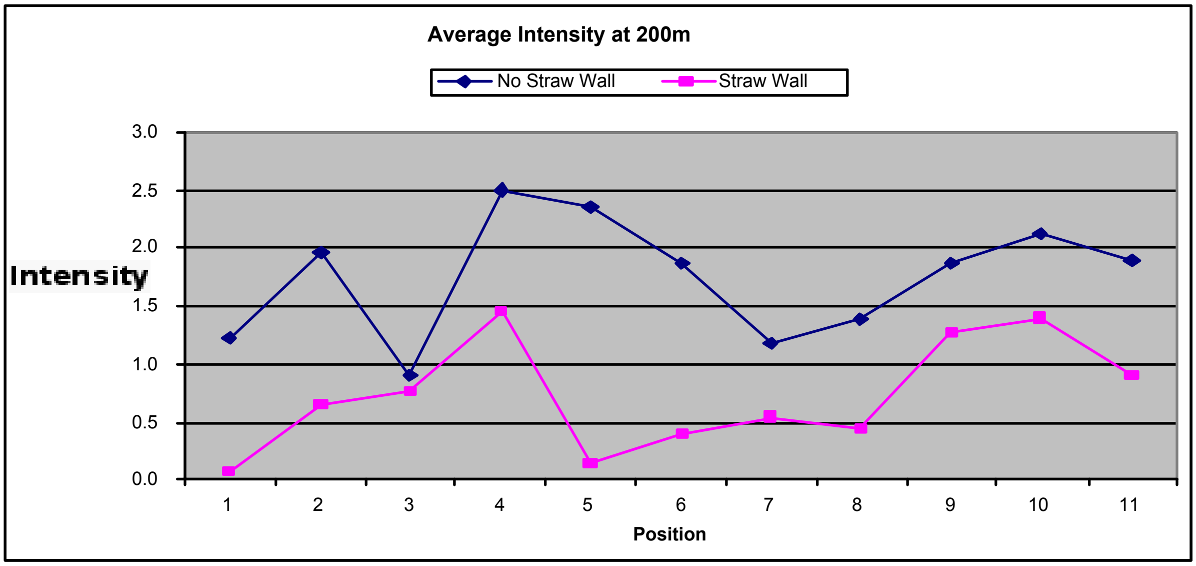

Figure 16a Odor intensity determined by trained sniffers at 200 meters downwind from a straw wall vs no straw wall

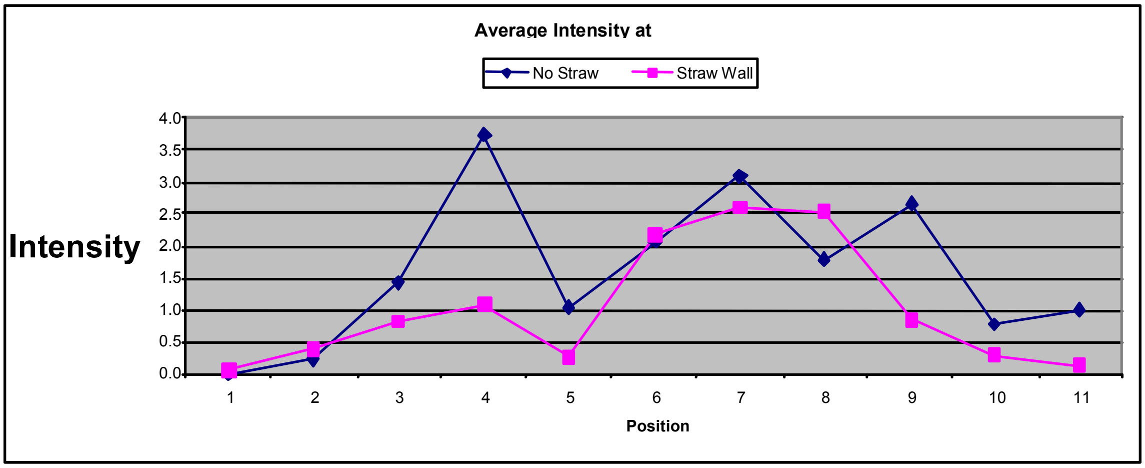

Figure 16b Odor intensity determined by trained sniffers at 25 meters downwind from a straw wall vs no straw wall.

Costs for the technology:

The costs for the large round bales vary considerably. The cost of transportation seems to the largest proportion of the cost if older bales of poor hay are used. Estimates ranged from $15 to $40 per bale. Most farmers have the equipment or can borrow equipment to place the bales into the barrier. Approximately 100 bales are needed per building housing 1000 finishing animals.

More Frequent Pumping of Swine Barn Manure Pit--Leader Philip Goodrich

Project subobjective: The objective of this research is to evaluate the effectiveness of more frequent pumping of swine manure from the storage pit beneath the barn.

The basic concept of more frequent pumping of the manure pit is that because there is less manure in the pit (depth is less) there are fewer microorganisms working on the manure and thus less odors and gases produced. Also the manure has less age (microorganisms have been had less time to break down the manure) and the resulting products are less offensive.

The researchers found that most producers wanted to pump their pits only when they were full. The task of pumping manure was to be done as infrequently as possible and that is why they had built the pits as big as possible. Finally one cooperator was found who was interested in lowering odors. One pit was pumped all the way down and the other was pumped only part way when the hogs were moved to market. The barns were refilled with pigs about fifteen days prior to sampling. Sampling was conducted only once and therefore these data are considered indicative only and caution should be used when evaluating this technology. After sampling was conducted, the regional fieldman for the owner of the hogs decided that we could no longer test on the farm.

The two barns were separate 1000 head buildings located away from other buildings. They were oriented end to end with fifty feet between buildings. They were standard curtain sided buildings with pits and fans on the pits. Samples were taken at the outlet of the operating fans in early May with the curtains partially closed.

The pit, which had been pumped down contained about 12 inches of manure, and the non-pumped pit contained about 34 inches of manure.

Samples were collected into Tedlar bags using the vacuum box. Hydrogen sulfide was measured using the Jerome meter and odor determinations were made in the laboratory within 48 hours using the olfactometer.

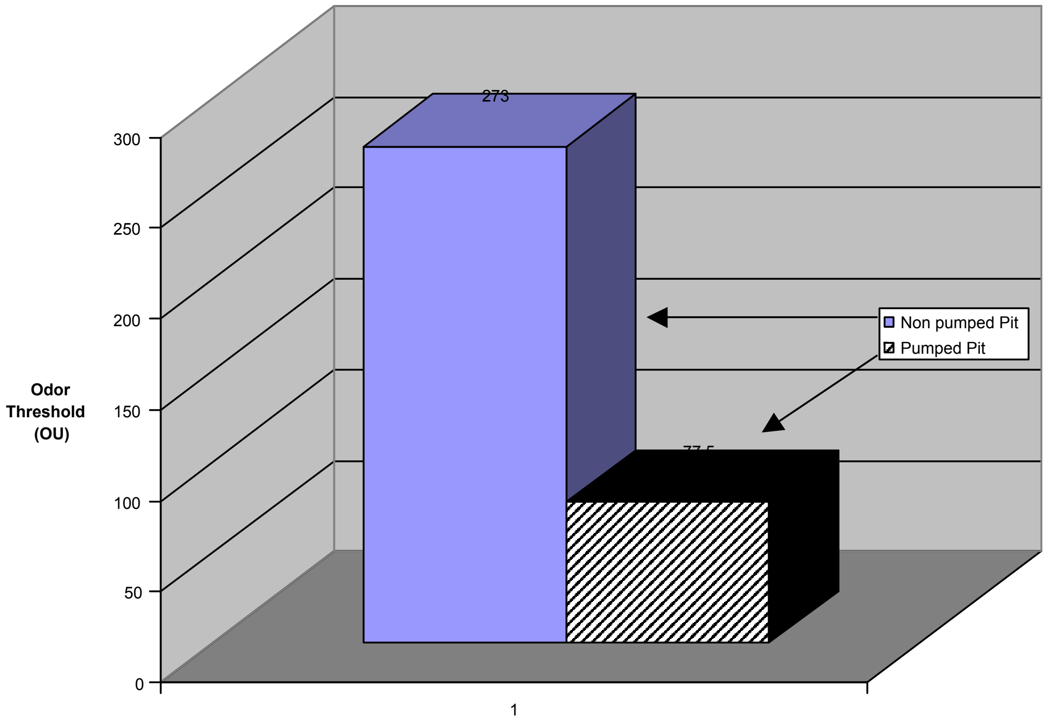

Figure 17 Threshold odor units for the pumped (12 in) and non pumped pits (24 in)

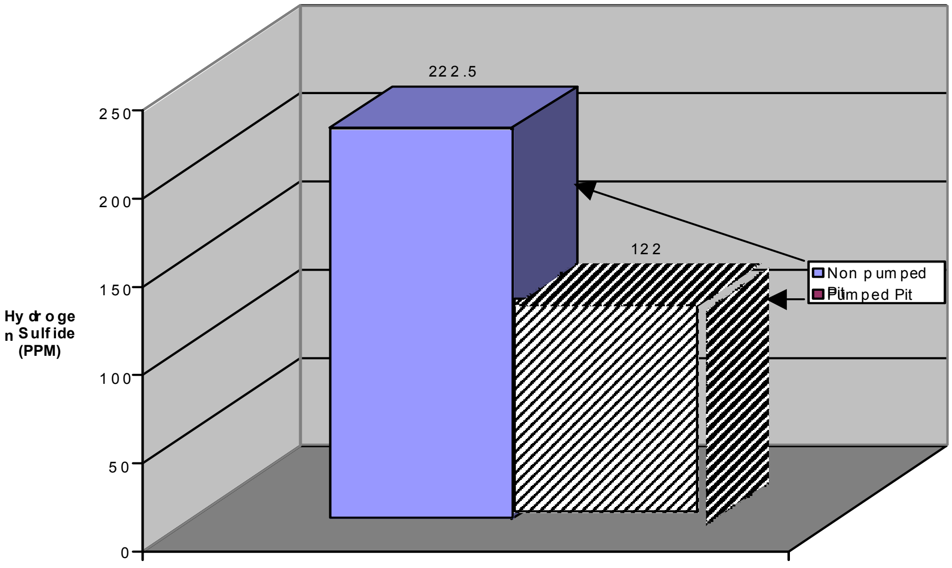

Figure 18 Hydrogen sulfide for the pumped (12 in) and non pumped pits (24 in)

Odor reduction and hydrogen sulfide reduction

The odor reduction is calculated using the equation:

$$\text{Percent Reduction} = (1-\text{treated}/\text{control})*100$$

$$\text{Percent Reduction} = (1-(77.5/273))*100 = 72\% \text{ reduction in the odor threshold.}$$

The hydrogen sulfide reduction was 45%. These are promising but the result of only one test on one building. The problems of land to apply and the impact on other operations on the farm seem to be strong factors in operator's unwillingness to even consider this management strategy.

Costs for the technology

There are no capital costs. The costs for hauling are the same if the costs are based on volume of manure to haul since the volume is the same. The costs may increase if the distance to haul is increased because local fields are unavailable at the time of hauling. The added cast for gearing up for hauling more than once per year are perhaps more psychological than actual, but do take some management time and may be at planting time or just after harvest and may be priced higher because of other management needs. A custom manure applicator may not provide the same volume discount because the setup costs are spread over a smaller volume of manure each time the tanks are pumped. It is estimated that the added cost would be less than $0.10 per hog finished to pump 2 times per year (spring and fall) and $0.20 to pump 3 times per year (early spring, midsummer, late

Experiments That Were Not Farm Based

Effect of Synthetic Amino Acid Supplementation and Diet Formulation Procedures on Odor and Gas Emissions in Grow/finish pigs---Leaders: J. S. Knott and G. C. Shurson

Subobjectives: The objectives of this study were to evaluate the effectiveness of using SID to formulate practical swine diets, which requires the addition of a precise balance of synthetic amino acids, on reducing odor, ammonia, and hydrogen sulfide emissions for grow-finish pigs.

Dietary manipulation is a potential approach that promises to be a partial solution for addressing the public and producer concern over livestock odor and manure nutrient management.

Most studies involving dietary manipulation have evaluated the addition of ingredients or substances to diets to alter microbiological and or digestive processes in the gastrointestinal tract. However, dietary manipulation can also involve managing digestible nutrient intake of the pig, which can result in less excretion of nutrients in manure and lower gas and odor emissions. By increasing the amount of synthetic amino acids such as lysine, methionine, tryptophan and threonine in the diet, less soybean meal is needed to meet the amino acid requirements of growing pigs, thereby reducing the amount of excess nitrogen in the diet. As a result less nitrogen would be excreted in the urine and feces, which can lead to a potential reduction in ammonia emissions from manure storage facilities.

Diet manipulation has been an effective, successful way of reducing gas and odor emissions. Hobbs et al. (1995) added synthetic amino acids to the diets of growing-finishing pigs to reduce the crude protein content of the diet. As a result, urinary nitrogen excretion was reduced, causing a reduction in ammonia emissions. Selecting feedstuffs and formulating diets that are low in excess sulfur and nitrogen, can reduce sulfur and nitrogen excretion, resulting in reduced hydrogen sulfide and ammonia emissions (Whitney et al., 1999; Sutton et al., 1999).

Another potential method to manage the odor created by pigs is by utilizing different formulation procedures. Currently, swine diets are formulated on a total or apparent digestible amino acid basis. These formulation techniques fail to account for endogenous amino acid losses from protein turnover in the gastrointestinal tract and endogenous secretions and are imprecise in maximizing nitrogen and sulfur utilization. Amino acids from protein turnover and endogenous secretions can be absorbed and provide for the pig's daily amino acid requirements. Therefore, by formulating on a total amino acid basis, diets contain excess nitrogen (amino acids) which is ultimately excreted by the pig. Standardized ideal digestibility (SID) formulation is a relatively new method that can be used to minimize excess amino acids in the diet. This method takes into account endogenous losses caused by specific feed ingredients and uses these values to determine amino acid values for that particular feedstuff (Rademacher, M. et al., 2000). Therefore, less amino acids are needed in the diet to achieve the pig's amino acid requirements. Additionally, formulating diets that optimize the ideal protein ratio will reduce excess amino acids in the diet. This has the potential to reduce nitrogen and sulfur concentrations in the slurry and may potentially reduce gas emissions such as ammonia and hydrogen sulfide.

Materials and Methods

Animals and Facilities

A total of 18 barrows with an average initial weight of 18.2 kg were used in a 16-week study. A total of eight pigs were assigned to each of two dietary treatments and pigs remained on their respective treatment group for the entire 16-week trial. More details of the experiments are available in Knott, and Shurson, (2001).

Diets

A single source of corn and soybean meal needed for the entire trial was identified and bagged. Samples were taken from every other bag, pooled and analyzed for amino acid concentration, dry matter, nitrogen, protein, fat, fiber, ash, energy and mineral composition. Diets were formulated on either a total or standardized ideal digestibility (SID) basis using on analyzed amino acid values. Two diets were fed in each of four phases (Grower 1, Grower 2, Finisher 1, Finisher 2). The control diet consisted of a "typical" corn-soybean meal based diet, formulated to total lysine recommendations and contained synthetic lysine. The experimental diet was formulated based on SID values according to Degussa-Huls recommendations and contained synthetic amino acids lysine, methionine, tryptophan, and threonine. Diets met or exceeded NRC 1998 mineral and vitamin recommendations. A table of the diets is available in Knott and Shurson (2001).

Manure Collection

All feces and urine excreted by each pig (n = 8) were collected daily, except on the days when feces and urine were collected to determine nutrient balance for each metabolism crate. Individual feces and urine collections were mixed thoroughly to ensure uniform consistency of each sample. Each collection was divided equally into four separate containers to achieve a total of 32 manure samples (4-samples/metabolism crate). The contents of each container were added to each of four deep pit simulation models (DPSM), giving a total of 32 DPSM for 8 metabolism crates (16 DPSM/treatment). The DPSM were constructed of PVC pipe and measured 2.1 m in height and 35 cm in diameter. The PVC pipe was set upright in a concrete filled basin to simulate a manure storage pit. The room temperature of the DPSM room was monitored and recorded daily and maintained as close to 62° F as possible. Additional details of the deep pit simulation models are available in Knott**,** and Shurson, (2001).

Odor and Gas Measurements

Air samples from each DPSM were collected weekly and analyzed for hydrogen sulfide concentration using a Jerome^{TM} meter. Ammonia concentrations were determined using the "boric acid" method. Air was bubbled through a 2% boric acid solution and titrated with sulfuric acid. Air was pulled at a flow rate of 40 L/min, approximated 10 inches off of the manure surface in each DPSM by an air pump and collected in kevlar-coated collection bags. Prior to the end of weeks 5, 10, and 15, air samples were also collected and analyzed for odor (odor detection level), odor intensity, odor offensiveness and persistence utilizing an olfactometer, intensometer, and human odor panel.

Results and Discussion

Hydrogen Sulfide Emissions

Hydrogen sulfide levels were analyzed through a logarithmic transformation by the statistical software Statistix^{TM}. Pigs fed the control diet had reduced ($P < 0.05$) hydrogen sulfide emissions during weeks 2 and 3 of the trial. These differences were lost as the DPSM equilibrated and a numerical trend was observed for lower hydrogen sulfide emissions from manure pigs fed the SID diets during weeks 13, 14, and 15 (Figure 19).

Note that low levels of hydrogen sulfide were emitted (Figure 19) until approximately week 6 of the experiment. This suggests that approximately 6 weeks is required to generate enough biological activity to produce significant amounts of hydrogen sulfide in the DPSM. The variation in peaks and crossing of the data points indicates the variation, which is expected in this biological model. It appears that pigs fed the SID diet produced manure, which was less capable of supporting microbes responsible for the production of hydrogen sulfide.

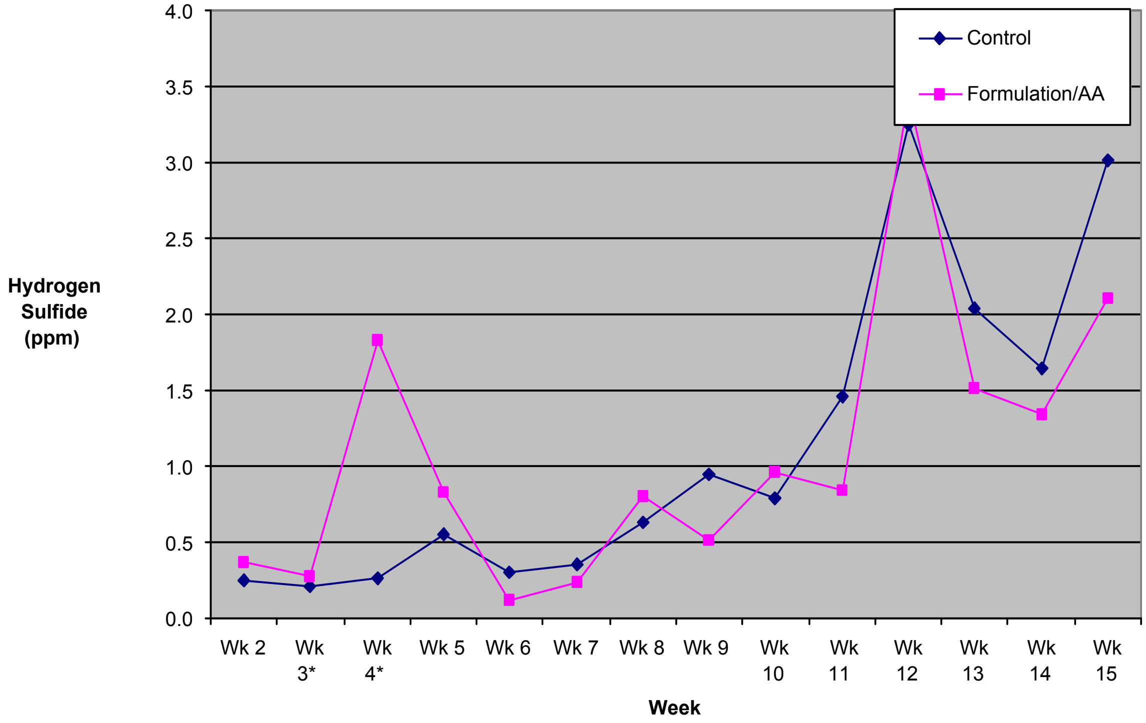

Figure 19-Effect of formulation technique and synthetic amino acids to grow-finish diets on hydrogen sulfide levels from deep pit simulator models

Ammonia Emissions

Ammonia is a gas that is volatilized when the nitrogen in urine comes in contact with the enzyme urease, which is present in feces. Ammonia is of concern in pork production systems because it can affect the health of pigs and people at high concentrations.

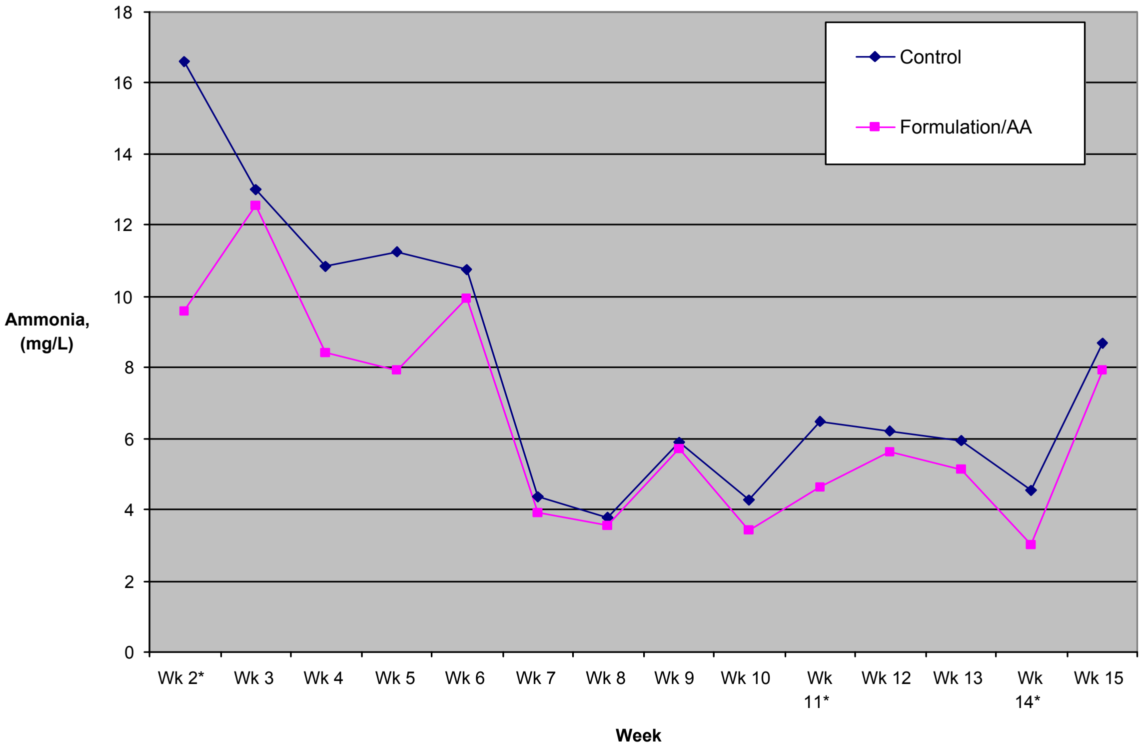

Figure 20-Effect of formulation technique and synthetic amino acids to grow-finish diets on ammonia concentration from deep pit simulator models

Throughout the entire trial ammonia concentrations were numerically lower for pigs consuming the SID diet. Ammonia concentrations were lower ($P < 0.05$) from manure of pigs fed the experimental diet for weeks 2, 11, and 14 (Figure 20). Ammonia and hydrogen sulfide gases are released under inverse environment conditions. When high levels of hydrogen sulfide are present, ammonia volatilization is reduced. As shown in Figure 23, ammonia levels appeared to be greater in the first 6 weeks of the trial, when hydrogen sulfide levels were relatively low.

Odor Emissions

Odor detection units (ODU) are a measure of the lowest detection threshold of odor detected by human panelists of an air sample. A low ODU indicates that high concentrations of the air sample is needed in order to detect an odor. Odor tests were conducted in the Olfactometry Lab in Biosystems and Agricultural Engineering.

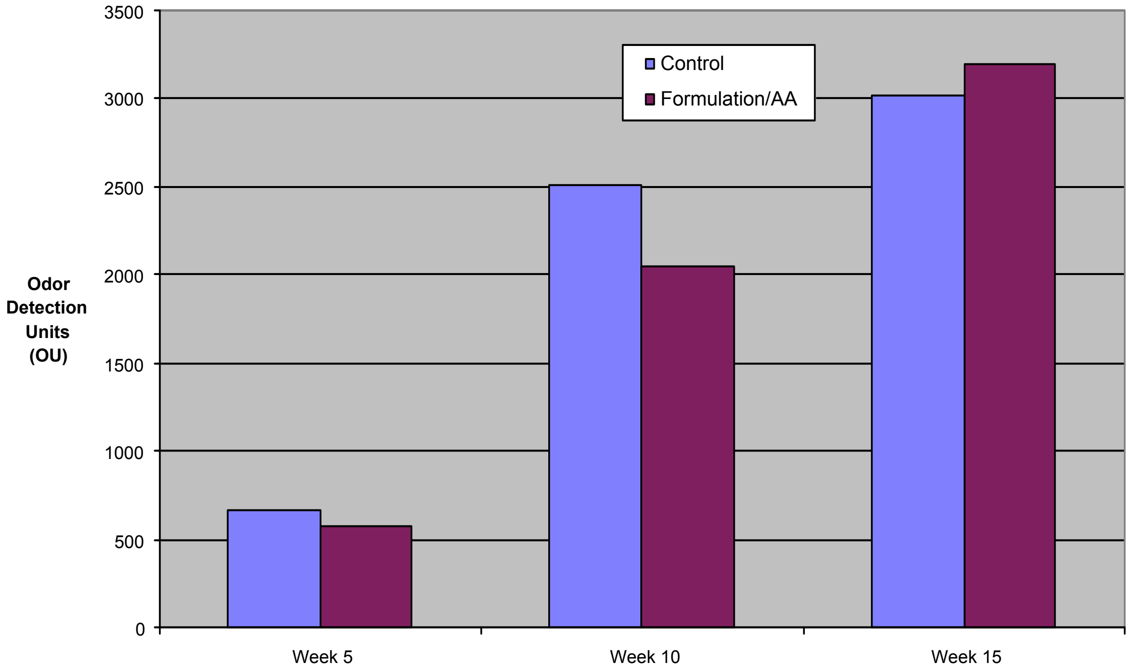

Figure 21-Effect of formulation technique and addition of synthetic amino acids to grow-finish diets on odor detection threshold (ODU) from deep pit simulator models

There were no differences in ODU of air samples collected in DPSM containing manure from pigs fed the control or the experimental diets (Figure 21). For weeks 5, and 10, manure from pigs fed the experimental diet had numerically lower odor detection levels as compared to manure from pigs fed the control diet. However in week 15, manure from pigs fed the control diet had numerically less detectable odor levels. Since there are over 200 odorous compounds in swine manure, it is not surprising that the experimental diet did not reduce odor detection level, despite a numerical trend for reducing ammonia and hydrogen sulfide emissions.

Odor Intensity

Odor intensity is a measure of how strong an odor is compared to an n-butanol standard. Panelists smell air samples through an intensometer at 8, 25 and 100% concentrated samples diluted with clean air. After smelling the samples, panelists assign each air sample with a number (1 to 5 scale) based on the intensity of the smell compared to the intensity of the n-butanol standard. A low number represents a less intense odor. There were no differences in odor intensity of air samples from manure of pigs fed the control and experimental diets (Figure 22). Manure from pigs fed the experimental diet had numerically lower odor intensity levels compared to control fed pigs for week 5. However, in week 10 and 15, both treatments had manure that had relatively the same odor intensity had less intense odors. This implies that SID formulation and supplemental amino acids were ineffective in reducing the intensity of odors emitted from swine manure.

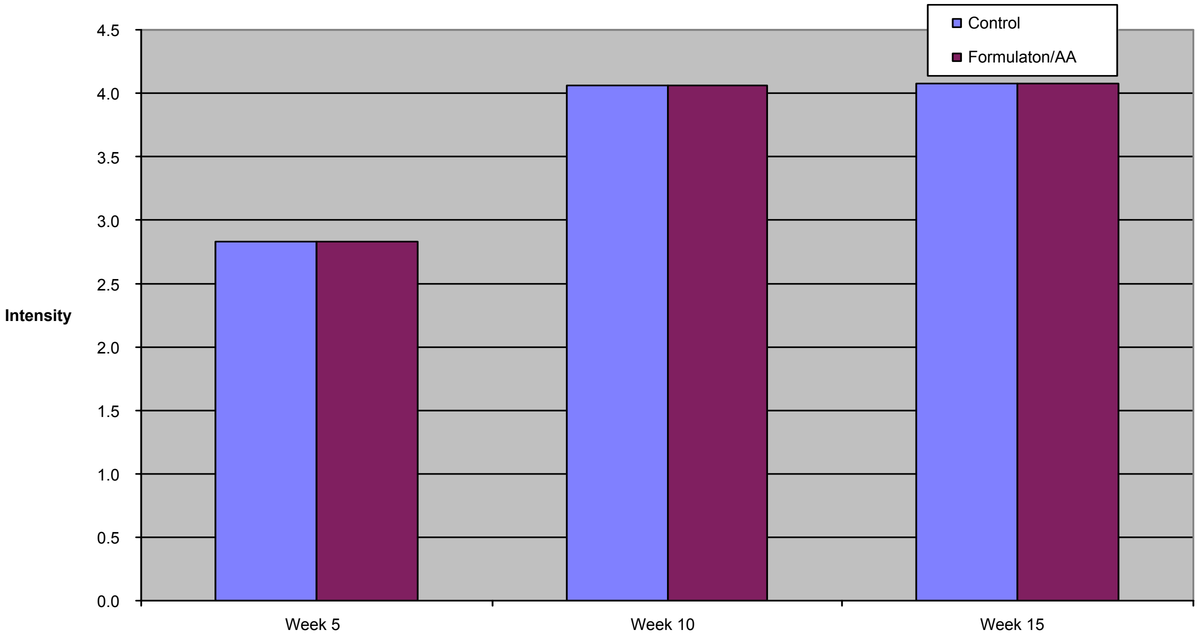

Figure 22-Effect of formulation technique and synthetic amino acids to grow-finish diets on odor intensity from deep pit simulator models

Odor Offensiveness

Hedonic tone measures the relative offensiveness of odors. Hedonic tone is important to measure because it portrays public perception to odors. Odor offensiveness is measured by human panelists, through an intensometer, who smell air samples diluted at 8, 25, and 100% concentration of the air sample. The panelist assigns a score based on the offensiveness of the odor on a numerical scale ranging from –4 to +4. A high negative number indicates that the smell is very offensive and a high positive number indicates that the odor has a very pleasant smell.

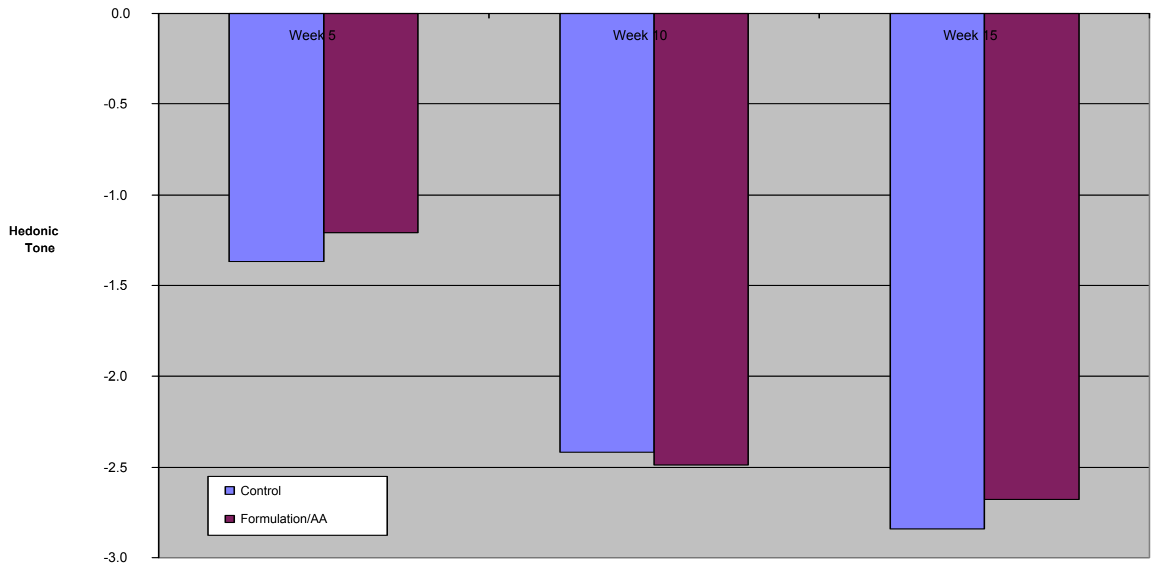

Figure 23-Effect of formulation technique and synthetic amino acids to grow-finish diets on hedonic tone from deep pit simulator 100% hedonic tone

There were no differences in odor offensiveness of air samples from manure of pigs fed the control or the experimental diet. This implies that formulation technique and supplemental amino acids had no effect on reducing the relative offensiveness of swine manure odors.

Odor Persistence

Odor persistence is a measure of the relative distance an odor will carry from the source of the odor. It is calculated by plotting the intensity of the odor against its concentration. Persistence measures the amount of dilution an odor can withstand before it is undetectable. Two odors may have the same intensity but have very different persistence values. The higher the number, the further the odor can travel away from its source and be detected.

There were no differences in odor persistence of air samples from manure of pigs fed either of the two diets (Figure 24). Manure from pigs fed the experimental diet had numerically lower persistence levels at week 5, but at weeks 10 and 15 the control pigs had less persistent odors. This indicates that SID formulation and supplemental amino acids were ineffective in reducing the persistence of odors emitted from DPSM.

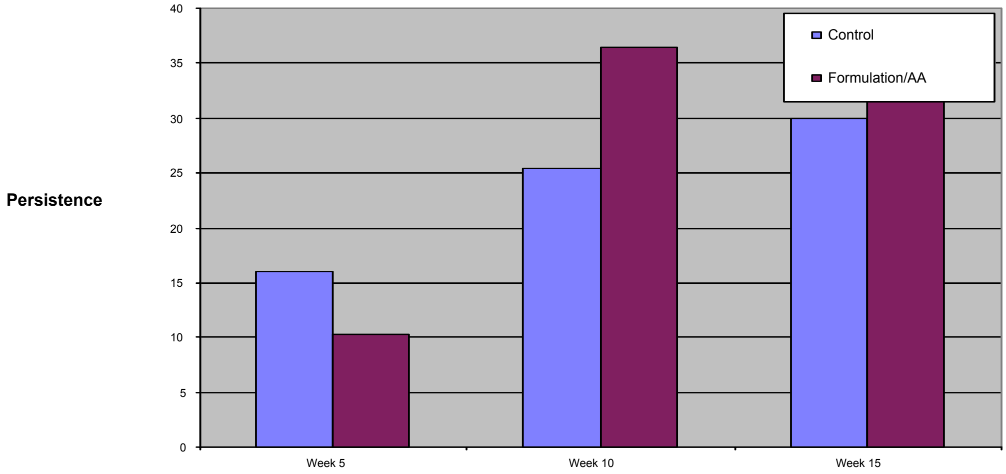

Figure 24-Effect of formulation technique and addition of synthetic amino acids to gro-finish diets on odor persistence from deep pit simulator models

Summary

The use of SID formulation and adding synthetic amino acids had no effect on energy and nitrogen digestibility and excretion. However, feeding the SID diet reduced slurry pH, ammonia emissions and tended to reduce hydrogen sulfide emissions during weeks 13-15 of the study. Although it appears that some benefit was obtained for reducing gas emissions, feeding the SID diet had no effects on manure odor detection, intensity or hedonic tone.

Nonthermal Plasma Treatment of Swine Gases--Leader: Philip Goodrich

Subobjective: To test a system of destroying gases and odors using electrical discharge called nonthermal plasma.

In this project a barrier discharge non-thermal plasma reactor was studied and developed for destroying dilute gases and odors generated by swine manure.

Pilot Reactor System Testing

A viable application of non-thermal plasma technique in swine odor control requires the system to be able to process a high flow rate of gas with an acceptable system size, capital investment and running cost. To meet these requirements, the system should be able to process dilute gases from an animal production facility of a defined concentration and flow rate at reasonable power consumption. The system should be easy to manufacture and be composed of durable materials.

A pilot odor reduction system was designed, constructed, and tested on swine odors from a storage pit.

The specifics of the materials, gap, length of reactor and number of cells are detailed in Wang, (2001). The reactor consisted of 12 cells, a power supply and a housing. Figure 25 shows the reactor as used in the project.

Figure 25. Photo of the pilot odor reduction reactor.

Pilot Reactor Field Testing

This project focused on measuring the two odor components H_2S and HN_3 reduction efficiency under the feed flow of the odor gas directly from a swine manure tank. The ozone in the byproduct was measured as well.

Measuring Ammonia Concentration

As discussed in Wang (2001), hydrogen sulfide measurement was done using two instruments and a modified method to remove the influence of ozone bleaching of the indicator was used for ammonia determination.

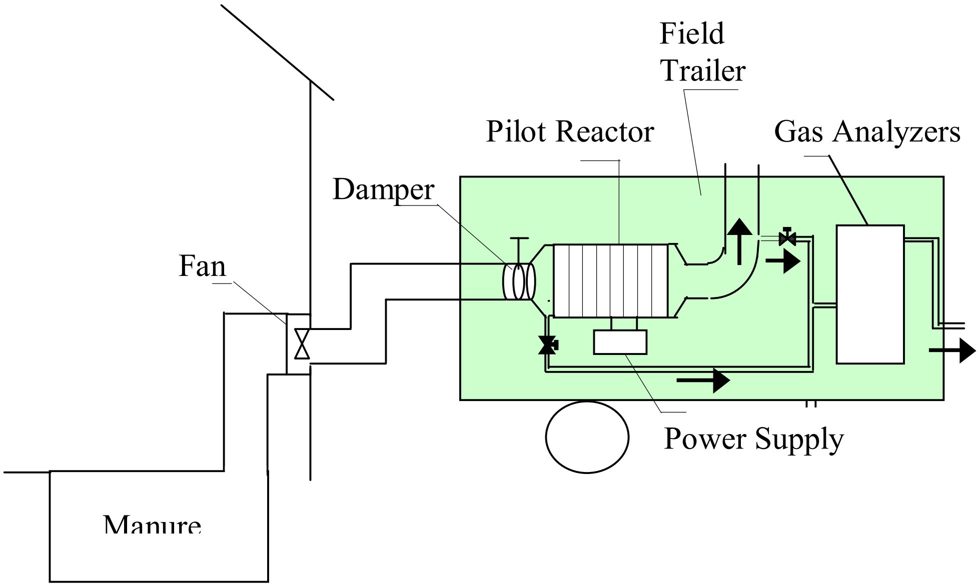

Figure 26. The layout of the field experimental system in the trailer.

Figure 27. The photo of the field experimental system connected to manure tank.

Figures 26 and 27 show views of the experimental system. For each trial air samples were taken for four different flow rates 5.7, 11.4, 17.1, and 22.8 m^3/min (200, 400, 600 cfm), respectively. At each flow rate, six samples were taken, three from input flow and three from output flow at the same time. In order to compare the removal efficiency of ammonia with different initial concentrations, a tiny flow of pure ammonia was added to increase the ammonia concentration in the feed flow. The flow was controlled by adjusting the regulator on the ammonia tank, and observing from the flow rate meter (Gilmont Instruments, Inc., Size No.11, Air 0 ~ 280mL/min). The two initial concentration levels are 27 ppm and 13.5 ppm. The data points shown in figures are the average of three samples.

Hydrogen Sulfide and Ozone Measurements

Experimental testing for hydrogen sulfide removal efficiency and ozone production was carried out with reactor, an ozone analyzer and Jerome meter with STI SO_2 scrubber, and STI Thermal Oxidizer II were employed in measuring the ozone generation, and the hydrogen sulfide concentration, respectively.

Hydrogen sulfide removal was first measured at low initial concentration, which was less than 5 ppm, using odorous air directly from the swine manure tank inside the waste management building. In order to measure the removal efficiency of a higher initial concentration, the manure in the tank was agitated to obtain an initial H_2S concentration from 30 to 50 ppm.

Results and Discussion

Hydrogen Sulfide Reduction Results

Figure 28 and 29 show the relationship of hydrogen sulfide removal efficiency and flow rate of the reactor. It is clear that at 5.7 m^3/min at both high and low initial concentrations of hydrogen sulfide, the removal efficiency was over 94%. When the initial concentration is less that 5 ppm, the removal efficiency at 5.7 m^3/min is more than 97%, and even when flow rate is as high as 22.8 m^3/min the removal efficiency is still 85%. For a higher initial concentration, in the range 30 ppm to 50 ppm, the removal efficiency at 22.8 m^3/min only reached 36%, but at 5.7 m^3/min 95% removal was achieved as well.

The reactor was designed to operate at 5.7 m^3/min and removal efficiency should be at least 75% when the initial concentration was as high as 100 ppm. These field test results were reasonable and the reactor was more effective than expected. One reason for this result may be that the applied voltage was a little higher than 10 kV, because the power supply was slightly over loaded. The other reason was that the design calculation was based on the results from a previous experimental study, when the H_2S initial concentration was more than 100 ppm.

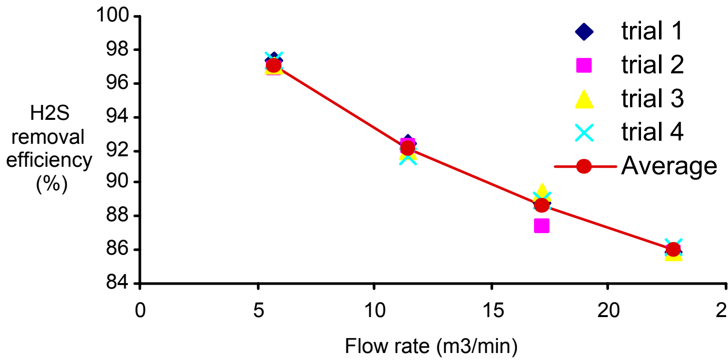

Figure 28. H_2S removal efficiency at low initial concentration (less than 5ppm).

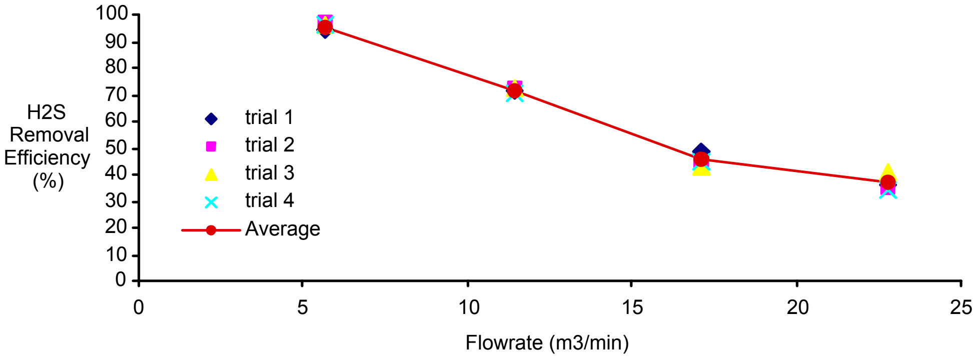

Figure 29. H_2S removal efficiency at high initial concentration (30~50ppm).

Ammonia Reduction Results

The ammonia removal efficiency data is presented in Figure 30 and 31. In Figure 30 the initial ammonia concentration was half as much as that in Figure 31, and at same flow rate the removal efficiency of Figure 30 was higher than that in Figure 31. For instance at flow rate 5.7 m^3/min, in Figure 30 the average removal efficiency was 96.6%, while in Figure 31 it was 87.5%. Therefore the same conclusion is the same as from the hydrogen sulfide data, the higher the initial concentration, the lower the removal efficiency at same flow rate of the reactor.

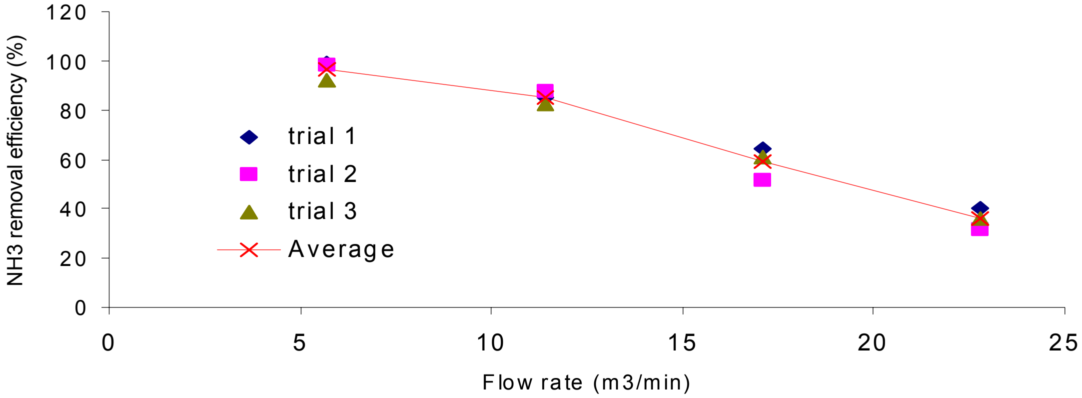

Figure 30. Ammonia removal efficiency when initial concentration was 13.5 ppm.

Inspecting the hydrogen sulfide removal data and the ammonia removal data we see that at the same flow rate and initial concentration of the two pollutants, hydrogen sulfide removal efficiency was higher than that of ammonia. The data in Figure 31 shows that when initial concentration of the ammonia was 27 ppm, at 5.7 m^3/min flow rate, the removal efficiency at most was 85.2%, while at a higher initial concentration of hydrogen sulfide, 30 to 50 ppm, the removal efficiency was at least 94%. The reason was that the ammonia dissociation energy was 4.3 eV and for hydrogen sulfide it was 3.26 eV. When the input energy was the same, hydrogen sulfide was much easier to remove, because of the lower dissociation energy.

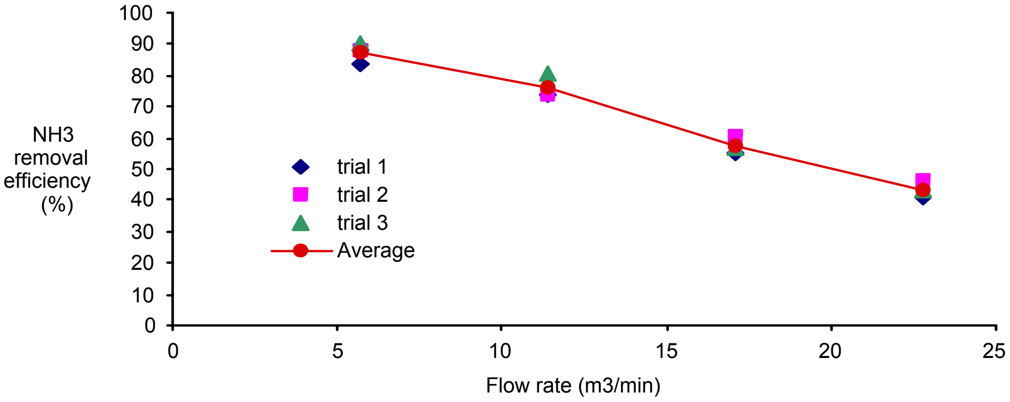

Figure 31. Ammonia removal efficiency when initial concentration was 27 ppm.

Conclusions

A prototype nonthermal plasma reactor with wire-to-plate geometry was highly efficient in removing H_2S and HN_3 at the specified flow rate 5.7 m^3/min. Field test results show that at a 5.7

m^3/min flow, for a H_2S with a initial concentration less than 50 ppm, the removal efficiency achieved was more than 95%. Even at the 11.4 m^3/min flow rate the removal rate can reach 70%. The HN_3 removal efficiency was also very good. When the initial concentration was less than 27 ppm, the removal efficiency was greater than 85%. The results show that the higher the initial concentration of the pollutant, the lower the removal efficiency. Normally, without agitation, the initial concentrations of H_2S and NH_3 exiting swine facilities are lower than the above levels, therefore the developed system should be adequate for improving the conditions at swine facilities.

Evaluation of Technologies

The financial and management aspects of new technologies are important in acceptance of technologies by producers. An Excel spreadsheet was developed to assess the cost effectiveness of several odor control technologies. The variable costs of operating technologies ranged from a few cents per marketed pig to $1 per pig. No attempt was made to evaluate the intangible benefit from the technologies to an individual operator. Producers must evaluate the costs/benefits of lost opportunity due to blocked expansion, community stress from challenges to production and management costs to process legal papers. Producers ultimately must decide what technology to use to satisfy local challenges.

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Appendix

Printouts of the Excel worksheet with costs for four systems follow. Producers may contact Dr. William Lazarus by email or by mail if they wish to use their own costs to evaluate these technologies.

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Adding Hydrogen Peroxide (H_2O_2) to the manure pit

System component treated: Manure treatment
Capital intensity of the technology: Minimal capital investment required

Initial investment items			
Total investment	$ -		
Estimated life, years	5		
Salvage value	0		Cost/year
Amortized capital service cost/yr			$ -
	Rate/$1 avg investment		
Property insurance	0.85%		-
Property tax	2.00%		$ -
Total ownership cost/year			$ -
Operating expenses			
Manure volume ft3 @ 200' * 41' * 7' deep assumed	57,400		
	gal./treatment	$/gal	
H2O2, 55 gal. drum, assume 490 lbs	55	$ 10	
Assume treatment 2x/year			1,068
Total operating expense/year			1,068
Total ownership and operating cost/year			$ 1,068

SOURCE: "Chemical Addition for Hydrogen Sulfide Control, Final Report, 8/31/01 (handout from 9/14/01 meeting, no author)

Biofilters

System component treated: Air
Capital intensity of the technology: Significant capital investment required:

Initial investment items						
	Number	Total investment				
Pallets (number @ $1.50/pallet)	270	$ 405				
Media (cubic yards @ $15/ cu yd)	150	$ 2,250				
Fan upgrade	8	$ 800				
Duct material		$ 2,000				
Sprinkler system		$ 500				
Labor to construct (man-hours @ $14/hr)	150	$ 2,100				
Total investment		$ 8,055				
					cfm	
Assume increased cfm of xxx for this addition (1000 head barn)					50,000	Assume turns/year 2.7
					(per 1000 cfm)	
Total investment/1,000 cfm	$ 8,055				$ 161.10	
Estimated life, years	20				cost/yr/	cost/pig finished
Salvage value	0			Cost/year	added 1000 cfm	
Amortized capital service cost/yr				$ 702	$ 14.05	
	Rate/$1 avg investment					
Property insurance	0.85%			34		
Property tax	2.00%			80.55		
Total ownership cost/year				$ 817	$ 16.34	$ 0.30
Operating expenses	Add hp		Elec. Rate $/kw-hr			
Electricity (additional fan horsepower required)	1.0		$0.065	$ 419	$ 8.38	
			# app/yr			
	Cost/application					
Weed spraying	$ 20		4	$ 80	$ 1.60	
			# app/yr			

	Cost/application					
Rodent control	$ 35		6	$ 210	$ 4.20	
Repairs (parts & labor)				$ 50	$ 1.00	
	Hrs/week	Weeks/yr	Rate/hr			
Labor for maintenance	0.50	26	$ 12.00	$ 156	$ 3.12	
Media and pallet replacement	Cost/replace		yr between rep			
	$ 2,000		5.0	$ 400	$ 8.00	
Total operating expense/year				$ 1,315	$ 26.30	$ 0.49
Total ownership and operating cost/year				$ 2,132	$ 42.64	$ 0.79

SOURCE: "Biofilter Treating Pit Exhaust on Deep Pit Curtin Swine Finishing Barn" (handout from 9/14/01 meeting, no author)

The detail on the investment items was provided by Dick Nicolai, 10/24/01 email.

David Schmidt added the per CFM analysis and (I believe) reduced the additional fan HP requirement from 1.25 to 1.0.

Assumptions:
Six 1/3 hp pit fans are increased to 1/2 hp to accommodate higher pressure drop
Biofilter system would last the life of the building (ie. 20 yr) but the media and some pallets would be replaced every 5 yr.
Repairs include duct and media maintenance. Not included are repairs to fans and motors since it would occur without a biofilter

1000 head curtain side finishing barn 41 ft x 200 ft.
Eight 24 inch diameter pit fans each exhausting 6000 cfm
Area of biofilter = 4000 ft^2 (180 ft x 22.5 ft)
Pallet cost of one dollar plus $0.50 transportation
Media cost $12 / cu yd plus $3 / cu yd transportation

Oil sprinkling, permanent installation using existing water sprinkling

System component treated: Air
Capital intensity of the technology: Minimal capital investment required

Initial investment items					
Injection pump, SHURflo8000 model 4UN55	$ 104				
Timer, Intermatic ET100C	57				
Timer, interval delay, Dayton 6X604	60				
Soleoid, Dayton general purpose	96				
					Cost/year
Total investment	$ 317				
Estimated life, years	5				
Salvage value	0				
Amortized capital service cost/yr					$ 75
	Rate/$1 avg investment				
Property insurance	0.85%				1
Property tax	2.00%				3.17
Total ownership cost/year					$ 80
Operating expenses	Cost/gal component	Mix	Cost/gal mix	Rate/day, gal.	
Product					
Soybean oil (Hi Energy Golden Liquid, OCCO Products), Liter	$ 3.29	95%	$ 3.13		
Surfactant, Alkamuls 600-DO (Rhodia Inc.), Liter	$ 17.41	5%	$ 0.87		
Oil and surfactant mix			$ 4.00	1.3	$ 1,897
Repairs (parts & labor)					$ 100
Labor for monitoring the system and filling oil tank					$ 50
Total operating expense/year					$ 2,047
Total ownership and operating cost/year					$ 2,127

SOURCE: Paszek, D.A., "Design and Management of an Oil Sprinkling System to Control Dust, Odor, and Gases in and from a Curtain-Sided Pig Finishing Barn," ASAE Paper 01-4076, presented 7/30-8/1/2001, Sacramento, CA

Ozone treatment of air

System component treated: Air
Capital intensity of the technology: Significant capital investment required

Initial investment items

	Total investment
DC corona discharge generator, 30 kilovolt	$ 10,000

		Cost/year
Total investment	$ 10,000	
Estimated life, years	5	
Salvage value	0	
Amortized capital service cost/yr		$ 2,374
	Rate/$1 avg investment	
Property insurance	0.85%	43
Property tax	2.00%	$ 100
Total ownership cost/year		$ 2,516
Operating expenses		
Electricity - 900 watts*24 hrs/day*365 days/year*.$07/kilowatt-hr		$ 552
Total operating expense/year		552
Total ownership and operating cost/year		$ 3,068

SOURCE: Philip Goodrich, U of M (personal communication), 11/29/01