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Abstract
The purpose of this project was to quantify the odor and gas emission benefits of a fine ground rubber cover on laboratory scale manure storage units and to evaluate the ability of a fine ground rubber cover applied to a commercial swine manure storage unit to remain intact and functional over an extended period of time. A three-inch cover of fine ground rubber reduced odors by 77 to 99 percent from the manure storage tanks over a six-week period. However, consistent reductions of NH_3 emissions were not observed and H_2S emissions from all manure storage treatments were below detectable limits. Assessments of the integrity of the fine ground rubber cover were promising for storage units in both the laboratory and field-scale trials.

Keywords Lagoon covers, storage covers, odor, ammonia, manure management

Introduction

The livestock industry has tried many kinds of covers for manure storages and lagoons. Numerous studies have demonstrated a decrease in odor and gas emissions by covering manure storages and lagoons with permeable and impermeable barriers. However, identifying cover options that are effective at controlling odors, low-cost, easy to install and maintain, and have a practical useful life remains a challenge. A new concept using fine ground rubber, an industrial by-product waste material of tire recycling, may provide an additional option for meeting these objectives. The goal of this project was to evaluate the performance and feasibility of a cover based upon finely ground rubber product before proceeding to full-scale field trials.

This project was completed as a part of a Phase I Small Business Innovation Research collaborative project funded through the US Department of Agriculture Cooperative States Research, Education, and Extension Service grant to Tire Recycling Centers USA, Inc. The University of Nebraska collaborated in the completion of the research components of the project.

Project Objectives

The overall goal of the project was to demonstrate the effectiveness of fine ground rubber as an odor control and abatement product for livestock manure storage structures. The specific objectives were:

- Quantify the odor and gas emission benefits of a fine ground rubber cover on laboratory scale simulated manure storage units and anaerobic lagoons.
- Evaluate the application of a fine ground rubber cover to a single commercial swine manure storage unit and monitor its ability to remain intact and floating over an extended period of time.

Literature Review

Many kinds and types of covers, both permeable and impermeable, have been evaluated for their ability to reduce odors from livestock manure storage facilities, each with unique strengths and weaknesses (Jacobson and Lorimor, 2001). A study of six alternative covers (Clanton et al., 1999) indicated that all covers reduced odor (as measured by dilution to threshold) and hydrogen sulfide concentration. Bundy et al. (1997) and Xue et al. (1999) concluded that chopped straw was an effective control option for odors and other related emissions. Cicek et al. (2004) observed that straw covers produced a negative impact on methane emissions and only modest value for odor control. Miner and Suh (1997) observed that 10 different polystyrene foam covers reduced ammonia emissions by 45 to 90%. A unique combination of recycled polyethylene and geotextile cover was observed to produce an 80% reduction in ammonia emissions and low odor emissions (Miner et al., 2003). Even natural crusting has been observed to reduce odors and other emissions (Bicudo et al., 2001)

Geotextile-based covers have gained some acceptance on commercial livestock facilities. Zahn et al. (2001) observed that a 0.3 cm geotextile and 0.32 cm closed-cell polypropylene foam cover reduced emission for ammonia and hydrogen sulfide from 15% to 60% over time as a biomass developed on the cover on a commercial swine lagoon. Bicudo et al. (2004) observed emission rate reductions of 90% for a geo-textile covered in its first year but declining performance in a subsequent year as keeping the cover afloat became an issue. Thus covers, especially those that provide a surface area for establishing a microbial biomass, provide excellent odor control for manure storages and lagoons. Issues of cost and life remain an issue as attempts to identify desirable alternatives continue.

Cost effectiveness of covers remains a challenge. Massey et al. (2003) noted that the cost of impermeable lagoon covers added $0.016 to $0.075 per kg to the cost of production, accounting for 14 to 65% of revenue for contract producers. A positive pressure lagoon cover was estimated to have an installation cost of $10.03 per m^2 and an operating cost of $12.30 per month (Funk et al., 2004a). A negative pressure lagoon cover was estimated to cost $3.75 per m^2 and an operating cost of $36 per month (Funk et al., 2004b)

Materials and Methods

Simulated manure storage and anaerobic lagoon

Seven treatments, five representing manure storages and two representing anaerobic lagoons, were established to meet the requirements of Objective 1. The manure storage tanks were set up in June, 2003. The six-week testing and sampling of manure storage units was completed July 30, 2003. The raw manure used in the lab-scale manure storage tanks was obtained from a university swine operation with a shallow, under-barn storage pit.

Treatments for measuring the effect of the fine ground rubber cover material on emissions from the manure storage units included:

(1) a control [manure storage with no cover];
(2) storage with 2.5-cm rubber cover [loaded below the surface to minimize break-up of the cover to approximate an exterior storage with loading below the surface];
(3) storage with 7.6-cm rubber cover [loaded as in Treatment 2];
(4) storage with a 7.6-cm rubber cover [with manure loaded through the rubber cover to approximate a pit storage below a slotted floor] and;
(5) storage full of water covered by 7.6-cm of rubber material [to determine the effect of rubber only on emissions and observe floatation characteristics of material].

Anaerobic lagoon tank experiments were started on July 23, 2003 after four weeks of acclimatization of the microorganisms in the tanks. Six weeks of testing and sampling was completed on August 27, 2003. Sludge, lagoon top water and manure for these experiments were procured from a commercial swine facility. Two different treatments were studied in the anaerobic lagoon experiments:

(6) a lagoon with 5.1-cm cover and
(7) a lagoon tank without the cover.

The treatment without the cover served as the control experiment. All experimental units (the tanks) were operated in triplicate.

The experiment was conducted in twenty-one 1360-liter polyethylene tanks measuring 2.4 m x 0.91 m x 0.91 m (see Figure 1). The manure storage units were initially loaded with 680-liters of manure. Twenty-three liters of fresh manure was added every week to each manure storage tank to simulate a one-year storage period. The anaerobic lagoon tanks were filled with 790-liters of lagoon top water and 110-liters of lagoon sludge. The simulated lagoons received fresh

Figure 1: Lab-scale tank experiments (manure storage and lagoon tank units).

manure at a loading rate of 0.48 kg of volatile solids per 1000 liter per day, the recommended loading rate for anaerobic lagoons in Nebraska (ASAE Standard EP 403.3, 2003).

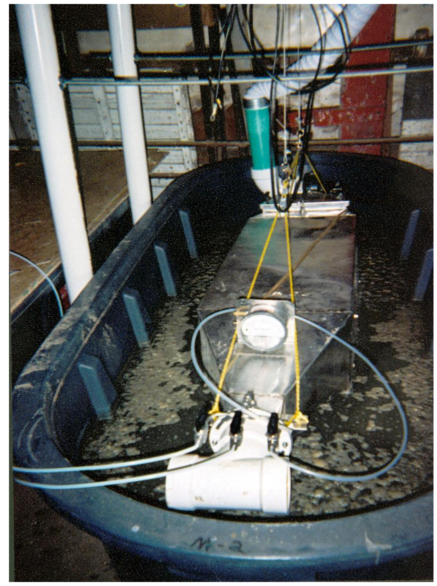

Figure 2: Wind tunnel set-up to measure emissions from the lab-scale tanks

Air Measurements- Simulated Systems

Weekly gas phase measurements included odors, ammonia (NH_3), and hydrogen sulfide (H_2S) for each of these treatments. Emission sampling was done using a wind tunnel (Figure 2) built by the University of Minnesota (Schmidt and Bicudo, 2002). The tunnel consists of an inlet stack for drawing air from outside the barn, a fan, an expansion chamber, an air filter, the tunnel body, a mixing chamber, an outlet baffle and three gas sampling ports. The tunnel is made with 24-gauge stainless steel to minimize the possibility of gaseous compounds sticking to its surfaces. The wind tunnel was calibrated prior to the beginning of this project for use in another research project that required measurement of emissions from feedlots and lagoons. The University of Minnesota performed this calibration using pressure drop to adjust air speed (m/s) in the tunnel. An air speed of 0.3 m/s across the surface was maintained in this project by adjusting pressure drop via controlling the area of the air inlet.

Air samples taken for olfactometry measurements were collected in ten-liter Tedlar bags using a Vac-U-Chamber (SKC-West, Inc., Fullerton, CA, Figure 3). The samples were sent overnight to the West Texas A & M University Olfactometry Laboratory (Canyon, TX) for next day analysis using a triangular forced-choice olfactometer (CEN Method 13725) designed to meet the ASTM Standard E679-91 and the European Standard ODC 543.271.2:628.52.

An acid bubbler, placed in a modified tool box, was used to obtain NH_3 samples by passing a portion of the air from the wind tunnel through 20 ml of 0.2 molar sulfuric acid for 30 minutes. Hydrogen sulfide was measured using a Jerome Meter (Model 631-X) from Arizona Instruments, Inc., Tempe, AZ. The Jerome meter measures H_2S, alkyl sulfides, disulfides, mercaptans and cyclic sulfur compounds. The meter response is reported as a H_2S equivalent (Koelsch et al., 2004) and is accurate to one part per billion (ppb).

Liquid Measurements- Simulated Systems

Wastewater characteristics, namely organic nitrogen, ammonium, total nitrogen, volatile solids, dry matter, and pH, for various treatments were measured at the beginning and end of the six-week experimental period. The liquid samples were then shipped for analysis by spectrophotometric determination to Ward Laboratories, Kearney, NE. Raw manure, lagoon top water and sludge samples, and manure storage samples were analyzed for total, organic and ammonium nitrogen, pH, volatile solids and dry matter of the liquid phase. Storage and lagoon temperature and pH were measured on site for each tank during air quality sampling.

The intactness of the rubber cover over the surface of each of the manure storage, anaerobic lagoon and control tanks was assessed visually as a percentage of the original cover that remained intact at the end of the 6-week experimental period. The intactness of the rubber cover was identified with a ‘yes’ or ‘no’ qualifier at the central point of each square of a rectangular grid on the surface of the cover. There were a total of 21 such points identified on

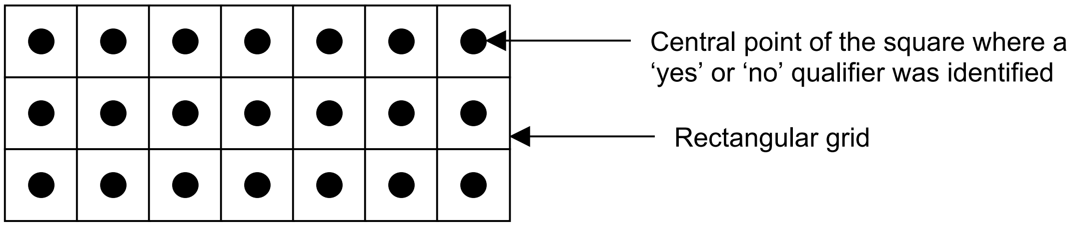

Figure 3. Top view of tank surface illustrating grid method used to assess intactness of the rubber cover

the surface of each tank as shown in Figure 3. The number of 'yes' qualifiers divided by the total number of central points yielded the percent intactness of the rubber cover for each treatment.

Field trial

A 33.5 meter diameter concrete-lined manure storage basin near Manning, Iowa was used for this portion of the project. The field trial was initiated in June of 2003 when no cover was present on the basin. Data collection began on June 27, 2003 and occurred again in July and October of that year. The basin was agitated on July 24, 2003 prior to application of the fine ground rubber cover material. Air samples were taken for odor, NH_3 and H_2S analyses prior to and 30-minutes after application of the material on that day. Figure 4 shows the equipment used to spread the rubber cover over the surface of the manure storage structure and the rubber cover after application at the field site. The field trial experiment was designed to provide data in support of the lab-scale tank experiments (Objective 1).

Emissions from the basin were monitored by Dr. Dwaine Bundy, Iowa State University, IA for odors, NH_3 and H_2S to evaluate the effectiveness of a fine ground rubber cover that was placed on the surface of the basin. Odor samples were obtained by floating an equilibrium chamber on the surface of the manure while pulling ambient air into the chamber and across the surface of the manure under the chamber. The chamber is the same type used to determine odor compliance of lagoons in Colorado. Air from the equilibrium chamber was pulled into a ten-liter Tedlar bag. The odorous air samples were evaluated within 48-hours at the Iowa State

Figure 4: Application of rubber cover on the manure storage structure at the field trial site in Manning, Iowa (left) and rubber cover after application on the manure storage (right).

University Olfactometer Laboratory. Samples from the air in the Tedlar bags were also taken to determine H_2S and NH_3.

The Triangular Forced-Choice Olfactometer (St. Croix Sensory, Inc) was used to evaluate the strength of the odor from the ten-liter Tedlar bags. Eight trained panelists in the ISU Olfactometry Laboratory evaluated odor strength. Odor strength was determined by evaluating the number of parts of fresh air that must be mixed with the odorous air sample to barely detect an odor (dilutions to threshold, DT). Odor intensity increases as DT becomes larger.

A Model 631-X Jerome meter (similar to that used in Objective 1) was used to determine H_2S levels. H_2S was measured in the Tedlar bags and on the berm of the storage structure. A Draeger PAC III was used to measure NH_3. It is accurate to one part per million (ppm).

Summary of Results

Results that address Objective 1

Wastewater characteristics, namely organic nitrogen, ammonium, total nitrogen, volatile solids, dry matter and pH, for each treatment were measured at the beginning and at the end of the experiments (Table 1). The pH was between 6.8 and 7.3 and generally increased slightly from the beginning to the end of the study. Addition of fresh manure to the manure tanks increased the organic nitrogen content, volatile solids and dry matter in the manure storage tanks. However, this increase was not observed in the lagoon tanks. Decreases in nitrogen compared to the initial characteristics were noted for the lagoon tanks.

Table 1. Wastewater characteristics at the beginning of each six-week experimental period

Treatment		Organic Nitrogen (ppm)	Ammonium (ppm)	Total Nitrogen (ppm)	Volatile Solids (mg/L)	Dry Matter %	pH
1. Storage: No Cover (Control)	Before	691	4,299	4,990	13,289	2.2	7.1
	After	3,322	3,140	5,706	33,600	5.6	7.3
2. Storage: 1-inch Cover (Below Surface Loaded)	Before	1,024	4,129	5,153	22,827	3.6	6.8
	After	1,903	3,922	5,306	31,832	5.8	7.3
3. Storage: 3-inch Cover (Below Surface Loaded)	Before	446	4,142	4,588	15,092	2.5	6.9
	After	3,000	3,855	5,758	46,110	8.0	7.0
4. Storage: 3-inch Cover (Surface Loaded)	Before	406	4,183	4,589	14,901	2.5	6.8
	After	2,687	3,883	5,339	31,469	5.7	7.0
Lagoon-top water	Before	132	902	1,034	1,580	0.5	8.1
Lagoon-sludge	Before	2,476	1,063	3,539	18,990	8.3	7.4
6. Lagoon: No Cover (Control)	Before	127	769	817	2,817	0.3	8.8
	After	19	703	722	2,783	0.4	8.8
7. Lagoon: 2-inch Cover	Before	146	769	824	3,250	0.6	8.5
	After	25	655	680	2,936	0.5	8.8

Odor reductions (compared to the control) due to the various rubber cover treatments are shown in Table 2. The 1-inch rubber cover resulted in more than 80 percent odor reduction during weeks 2, 3 and 6 on the simulated storages. Odor reduction in week 4 was low, and non-existent in week 5. Odor reduction of 77 to 99 percent was observed with the 3-inch rubber cover irrespective of the mode of addition of the manure to the storage tanks. A decrease in odor reduction was observed for the 3-inch surface loaded treatment in the fifth and sixth weeks, possibly due to the partial break-up of the rubber cover (see Table 2 for odor reduction and Table 6 for intactness of cover).

Table 2. Percent odor reduction in the manure storage tank experiments for the six-week period

Treatment	1 No Cover (Control)	2 1-inch Cover		3 3-inch Cover		4 3-inch Cover		5 3-inch Cover & Water
	(DT)	(DT)	% Reduction	(DT)	% Reduction	(DT)	% Reduction	(DT)
Week 1	43	22	49	13	70	18	58	43
Week 2	163	29	82	29	82	24	85	-
Week 3	396	36	91	18	95	21	95	-
Week 4	1526	1001	34	16	99	21	99	-
Week 5	554	554	0	35	94	130	77	23
Week 6	812	158	81	44	95	148	82	

An overall increase in NH_3 concentration (from 32 μg/m^3 to 627 μg/m^3, Table 3) was observed over the six-week period for Treatment 1 with no rubber cover, which was the control experiment for the storage treatments. Treatments 2 (1-inch) and 4 (3-inch) showed an increase followed by a decrease in the NH_3 concentration at the surface. Compared to the control (Treatment 1), Treatments 2 and 4 showed an 80 percent decrease in NH_3 concentration during the sixth week. The NH_3 concentration for Treatment 3 became steady at about 550 μg/m^3 in the third week. A 13 percent reduction in NH_3 concentration resulted for this treatment in the sixth week.

Table 3. NH_3 (μg/m^3) and H_2S (ppm) levels in the air above the manure storage tanks.

Treatment	1 No Cover		2 1-inch Cover		3 3-inch Cover		4 3-inch Cover	
	NH_3	H_2S	NH_3	H_2S	NH_3	H_2S	NH_3	H_2S
Week 1	32	ND	55	ND	25	ND	67	ND
Week 2	0	ND	0	ND	43	ND	250	ND
Week 3	0	ND	0	ND	0	ND	0	ND
Week 4	507	0.005	640	ND	553	ND	575	ND
Week 5	523	ND	493	ND	507	ND	541	ND
Week 6	627	ND	119	ND	547	ND	125	ND

ND – Not detected

H_2S was non-detectable in the air for nearly all treatments (Table 3). Thus, these results are inconclusive for demonstrating the effectiveness of the rubber cover in reducing H_2S emissions. It is not clear how much, if any, H_2S was being produced in the tanks. Low H_2S concentrations could also result from the 0.3 meter/second air flow-rate across the wind tunnel. Further studies were conducted to rule out the latter. An equilibrium chamber was placed on the surface of the lagoon treatment with no cover. H_2S concentrations were recorded once every 5-minutes for one hour using the Jerome meter. Non-detectable H_2S concentrations were also observed over this sampling period leading to the conclusion that there was minimal H_2S emission from the uncovered liquid manure surface. The possibility of the Jerome meter not functioning accurately was ruled out based on H_2S concentrations measured on actual lagoon surfaces by the same meter in a different study carried out during the same six-week period as this project.

Odor reductions (compared to the control) achieved each week for the 5.1-cm anaerobic lagoon rubber cover treatment are shown in Table 4. The rubber cover resulted in an average odor reduction of 44 percent. Week 3 data was not included when calculating the average reduction because the detection thresholds were near the lower limits of the olfactometry equipment. In general, the odor levels from the lagoon tanks were very low throughout the six-week experimental period.

Table 4. Percent odor reduction in the anaerobic lagoon tank experiments for the six-week period.

Treatment	6 Lagoon No Cover (Control)	7 Lagoon With 2-inch Cover	
	DT	DT	% reduction compared to 6
Week 1	46	19	59
Week 2	26	20	23
Week 3	15	18	-20
Week 4	26	25	4
Week 5	119	50	58
Week 6	87	20	77

Ammonia concentration in the air at the surface of the lagoon treatments was generally higher than that of the manure storage treatments (Tables 3 and 5). There was a several-fold increase in NH_3 concentration in Treatments 6 and 7 over the first three weeks, and those higher levels persisted through the remainder of the trial. The rubber cover was not effective in reducing the NH_3 emissions as indicated by comparing the NH_3 concentrations of Treatment 6 to those of Treatment 7 (Table 5). Below detection results for H_2S emissions from Treatments 6 and 7 for all six weeks (Table 5) prevent any conclusions regarding percent reduction in H_2S emissions due to the rubber cover.

Table 5. NH_3 ($\mu g/m^3$) and H_2S (ppm) in the anaerobic lagoon tank experiments for the six-week period.

Treatment	6 Lagoon - No Cover (Control)		7 Lagoon - 2-inch Cover	
	NH_3	H_2S	NH_3	H_2S
Week 1	500	ND	500	ND
Week 2	753	ND	280	ND
Week 3	1293	ND	1487	ND
Week 4	1247	ND	1240	ND
Week 5	1167	ND	1707	ND
Week 6	1180	ND	993	ND

ND- Not detected

The rubber covers for the manure storage tank with 2.5-cm rubber cover, the anaerobic lagoon tanks with 5.1-cm rubber cover, and the water tank with 7.6-cm rubber cover all remained intact at the end of the six-week experimental period (Table 6). The manure storage tank with 7.6-cm rubber covers had less than 100 percent intactness at the end of the experiments. For the tanks simulating outdoor storage units, 70-75 percent of the cover was intact while only 30-40 percent of the cover was intact for the tanks representing a pit below a slatted floor. It appears that dropping manure through the 7.6-cm cover was detrimental to the intactness of the cover. Loading below the surface was less detrimental but the 7.6-cm cover also had trouble staying intact.

Table 6. Intactness of the rubber cover over the surface of each treatment tank after the six-week experimental period

Treatment	Intactness of rubber cover (%)
1. Storage – No Cover (Control)	-
2. Storage – 1-inch Cover	100
3. Storage – 3-inch Cover – Below Surface Loaded	70-75
4. Storage – 3-inch Cover – Surface Loaded	30-40
5. Water – 3-inch Cover	100
6. Lagoon – No Cover (Control)	-
7. Lagoon - 2-inch Cover	100

Results that address Objective 2

The data for this portion of the project were taken from June 27 to October 22, 2003. Table 7 shows the results for odor detection threshold, H_2S and NH_3 using the equilibrium chamber before and after application of the rubber cover material. The shredded rubber material that was put on the basin became very hard on the surface. When the chamber was placed on the rubber, there was essentially no indentation in the cover. The bottom part of the cover, which was approximately 7.6-cm thick, remained soft.

Table 7. Air monitoring results at the slurry basin surface, with and without a rubber cover.

Date	Activity	Odor Detection Threshold	Reduction[1] (%)	H_2S (ppm)	Reduction[1] (%)	NH_3 (ppm)	Reduction[1] (%)
6/27/03	uncovered basin	3092		34		134	
7/24/03	uncovered basin w/agitation	8257		> 50		> 410	
7/24/03	covered	303	90	0.026	99.9	2	98.5
10/2/03	covered	116	96	0.23	99.3	31	76.9
10/22/03	covered	396	87	0.023	99.9	16	88.1

[1] Covered estimate compared to uncovered basis without agitation.

The field observations show substantially lower odor threshold levels (87 to 96 percent) as well as lower H_2S (99 percent) and NH_3 (77 to 98 percent) concentrations at the basin surface and down wind of the basin after installation of the cover (Table 7). Multiple factors could have contributed to these reductions, including changing atmospheric conditions and storage basin properties, as well as the effect of presence of the cover. These possibilities, and the limited amount of data gathered, prevent definitive conclusions. However, the trends observed at the field application site are supportive of the observations made in the laboratory studies. Significant reduction in odor and gas emissions following installation of the rubber cover in the laboratory also appeared to occur at the field installation.

The odor detection threshold of the rubber cover material itself, prior to installation was 328. This is an odor intensity similar to that of the readings taken after the cover had been installed (Table 7 on 7/22, 10/2, and 10/22). It is not known what the effect of aging of the rubber material had on the inherent odor emissions from the cover itself. A slight reduction in odor control effectiveness appeared in the last set of readings (10/22/03) compared to the readings three weeks earlier; however, the integrity of the cover appeared to be the same. This was not the case with H_2S and NH_3. Both showed continued large percent reductions compared to readings from the uncovered basin.

A second set of H_2S and NH_3 measurements were made on the berm of the basin (Table 8). At this location, H_2S readings showed a 54 percent reduction when the cover was in place. Ammonia levels were below the one ppm detection limit of the Draeger instrument in both cases. While only trends can be observed from the data taken on the berm, these observations support the results of both the laboratory study and those of the equilibrium chamber results of the field trial.

Table 8. Air monitoring results on the downwind slurry basin berm, with and without a rubber cover.

Timing Relative to Cover Installation:	H_2S		NH_3
	(ppm)	(% Reduction)	(ppm)
Prior to cover	0.052		< 1
After cover	0.024	54	< 1

Conclusions

The three-inch fine-ground rubber cover reduced odors by 77 to 99 percent from manure storage tanks over a six-week period. However, consistent reductions of NH_3 emissions from the storage tanks with rubber cover were not observed. H_2S emissions from the manure storage tanks were below detection limits. Thus it is not possible to arrive at any conclusions regarding H_2S reduction as a result of the rubber cover in the laboratory portion of this study.

Odor levels observed from the lagoon tanks with rubber covers were very low throughout the six-week experimental period. An average of 44 percent odor reduction was observed for the lagoon treatment with two-inch rubber cover over the six-week period. No reduction in NH_3 was noticed for the lagoon treatments. H_2S emissions from the lagoon treatments, with and without the rubber cover, were below instrument detection limits.

The fine ground rubber cover was found to be effective in reducing odors from the field trial manure basin, which was assessed over a four-month period. Substantially reduced NH_3 and H_2S emissions were also recorded during the manure storage basin field trial.

Assessments of the integrity of the cover were very promising for storage units in both the lab-scale and field trial tests. Some loss of the ground rubber material was observed on the laboratory scale storage units over the six-week trial. The entire manure storage basin remained covered with the rubber material throughout the field study.

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