# FINAL REPORT

## SUBMITTED TO THE
## IOWA PORK PRODUCERS ASSOCIATION

### FOR THE PROJECT

# PARTIAL BIOFILTRATION FROM A CURTAIN-SIDED DEEP-PIT SWINE FINISHER

### PRELIMINARY FINAL REPORT: APRIL 11, 2007
### FINAL REPORT: SEPTEMBER 28, 2007

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## I. Objectives of Research Project

The objective of this research project was to develop a biofiltration strategy that could be implemented by producers to filter a "critical minimum" amount of ventilation air from curtain-sided deep-pit swine finishers. To propose 100 percent biofiltration of ventilation exhaust air for high ventilation rates is not feasible for most producers. However, a strategy to treat a critical minimum amount of ventilation air by biofiltration could maximize the emissions reduction benefit at the lowest possible cost. Specific objectives of this research project were to;

1). Retrofit an existing curtain-sided deep-pit swine finisher for biofiltration of a critical minimum amount of the hot weather ventilation rate,

2). Monitor emissions of hydrogen sulfide, ammonia, and odor from a biofiltered barn and compare these emissions from an on-site control barn without biofiltration, and,

3). Provide design recommendations for critical minimum biofiltration strategies.

## II. Description of Research Project

This research project investigated the gas and odor emission reduction potential from a deep-pit swine finisher using a strategy of partial biofiltration. The key idea is that ventilation air exhausted during the heat of summer days is exhausted into an atmosphere that is, for the vast majority of times, very unstable thus providing excellent and natural mixing potential near the building source. In more stable atmospheres, typically present during the evening hours, biofiltration of a critical minimum amount of ventilation air would reduce gas and odor emissions during those times when the potential for odor plumes to travel long distances is greatest. The overall effect could be a more attractive and affordable biofiltration strategy that maximizes odor and gas reduction potential when it is needed most.

Our experimental design is best described as a monitoring and evaluation research effort. Two side-by-side deep-pit swine finishers located at a cooperator's site near Stratford, IA were used to

conduct this research project. Real-time emissions of ammonia and hydrogen sulfide with periodic odor measurements were collected over the summer periods of 2005 and 2006. Electrical energy usage and emission reduction comparisons were made between the control barn and the biofiltered test barn during these two periods.

## III. Benefit of Research to Industry

This research project will address an important biofiltration strategy that could be used to reduce emissions from swine production systems and simultaneously reduce concentrations of odorants off-site during the most stable atmospheric conditions that can give rise to the most incidences of odor complaints. If this mitigation method is successful in reducing emissions and odors, this would give producers a lower cost method for gas and odor mitigation from fan ventilated swine housing systems. This method could also be implemented in curtain-sided barns with pit ventilation, provided the biofiltered air *via* fans meets or exceeds the critical minimum ventilation rate.

## IV. Literature Review - Current Status of Problem

Odor and gas dispersion from swine facilities is receiving much attention. Sources of odor and gas emissions include land application of slurry, manure storage facilities, and the building. Much of the past effort in source reduction has been devoted to minimizing odor release from land application and storage facilities. Injection techniques for slurry and covers for manure storages are both viable options that have been shown to be very effective in reducing off-site gases and odors.

As land application and storage source reductions continue to progress, the remaining source for odors becomes the building itself. Ventilation air is typically exhausted into the ambient atmosphere without treatment. This exhaust air contains odorous gases, moisture, animal dander, and feed dust particles, and can represent a concentrated odor source.

Many researchers have examined odors from livestock facilities to determine the constituents that are most influential in olfactory perceptions. Hammond *et al.* (1979) found that the most important compounds were acids, phenols and carbonyls. However, results indicated that odors occurring at large distances from animal facilities were amplified by the presence of dust particles. Hartung (1985) stated that filtering the dust from exhaust air can reduce the odor emission from animal houses up to 65 percent.

Biofiltration is a technology that can treat a wide spectrum of gaseous compounds. Although not a new technology, biofiltration is an adaptation of a natural atmosphere-cleaning process. Biofiltration uses microorganisms to break down gaseous contaminants and to produce non-odorous end products. The process combines the sorption of activated carbon, the washing effect of water, and oxidation. As the air passes through the biofilter media, the odorous gases come into contact with the media.

Biofiltration works well for treating odors and contaminated gases from livestock sources because an uncharacterized population of microorganisms can adapt to the profile of compounds to be treated. By-products are primarily water, $CO_2$, mineral salts, and oxidizable inorganic compounds. Biofilters can remove up to 90% of the odor, 95% of the hydrogen, and 60-75% of the ammonia emissions from a livestock source. Thus, biofiltration is an effective technology to improve air quality adjacent to livestock facilities. Biofilters are relatively economical and simple to install and maintain, but require a large land area and may require higher capacity fans to move the ventilation air to be treated through the filter material, depending upon the media used.

Noren (1985) used peat and heather over wooden slats to form a biofilter for animal housing. It was found that odors were absorbed and converted by microorganisms to odorless substances after the biofilter was allowed to mature. Gases were decreased at an average rate of 50 percent with an 80 percent removal rate when the biofilter was kept at an optimal moisture content. Zeisiz and Munchen (1987) used several different materials including humus soil, compost, and peat. O'Neill and Stewart

(1985) summarized the effectiveness of biofilters showing the odor removal efficiency ranged from 50 to 90 percent.

## V. Related Research by Principle Investigators

The PI and Co-PIs listed in this research project have had significant experience studying both swine house ventilation strategies and the design, evaluation, and practical use of biofiltration. The Co-PIs Janni, Nicolai, Schmidt, and Jacobson developed biofilter design criteria for U.S. ventilation systems and have had significant experience in the design and implementation of biofilters on Minnesota swine production systems. Co-PI Harmon has significant experience in swine housing systems, including ventilation systems, and understands on-farm management issues. The PI Hoff has had extensive experience in swine house ventilation design and in the collection of emissions data from swine facilities and the resulting off-site gas concentrations that result from these emissions.

Research that has been conducted in the past related to gas emissions from swine housing indicates that significant changes in the ventilation rate occur over each day in order to maintain the internal climate for the pigs at target conditions. For example, it is not uncommon during the heat of the summer for the ventilation rate to change from 35 fresh-air-changes per hour (ACH) in the evening to a maximum of 100 ACH during the heat of the day. To biofilter all ventilation air (i.e. 100 ACH) would be cost prohibitive. In addition, the maximum ventilation rates experienced during the heat of the day are being exhausted to an atmosphere that is, for the most part very unstable, resulting in a significant amount of mixing and dilution close to the source. Likewise, during more stable and cooler evening hours, a lesser amount of ventilation air is required to maintain the internal building climate required by the animals. This change in ventilation requirements, as a function of atmospheric stability, can be used to an engineer's advantage with respect to biofilter design.

During the cooler and more stable evening hours, odors and gases exhausted from buildings have the potential to travel greater distances than those exhausted during the unstable daytime hours. Therefore, it makes practical sense to biofilter the critical ventilation air that will experience stable atmospheric conditions, and avoid treating air exhausted during unstable atmospheric conditions subjected to natural and effective atmospheric dispersion and mixing. This strategy will serve two useful purposes; first, the amount of air required for biofiltration will be significantly less than the total ventilation rate designed for the housing system, and second, the end result will be a reduction in source emissions of key pollutants that are currently being reviewed by the USEPA.

This research project proposes to define a "critical minimum" ventilation rate that encompasses, for the majority of the time, ventilation air that is delivered during the more stable evening hours, and, not treating air exhausted from fans or curtains that predominantly operate only during the more unstable hot daytime periods. Figure 1 highlights this trend. Figure 1 is a randomly selected two-day period (August 17-18, 2003) of a swine deep-pit finisher monitored for the Six-State USDA-IFAFS funded "Aerial Pollutant Emissions from Confined Animal Buildings" (APECAB) project (Jacobson, PI). Figure 1 shows the changes in building ventilation rate with changes in outdoor temperature. For both days shown, the ventilation rate was at its maximum (82,000 cfm = 70 ACH = 86 cfm/pig) during the hot periods of mid-day as would be expected. However, during early evening, evening, and early morning hours the ventilation rate throttled back to a rate between 30,000 and 52,000 cfm (25-42 ACH = 31-54 cfm/pig). It is the ventilation air that predominates during summer-time evening hours that we propose to biofilter, leaving the remaining ventilation air to disperse and dilute naturally with the corresponding unstable day-time atmospheres.

## VI. Procedures to Achieve Objectives

The procedures followed to complete this research project were as follows:

A. Objective One. Our analysis of the ventilation rate variations throughout a typical Iowa summer indicate that the ventilation rate, at it's maximum, occurs roughly 14 percent of the time. During this

period of time, solar conditions are generally high and the atmosphere is very unstable resulting in excellent vertical mixing of emissions near the source, lessening the odor impact downwind. During more stable, cooler summer evenings, the ventilation rate on average reduces by roughly 60 percent. Therefore, to maximize the benefit of biofiltration, and minimize fan operation costs, we propose to biofilter only that portion of the ventilation system that is active most of the time during summer evenings when the atmosphere is stable and the potential for odors to travel greater distances is highest. In this manner, a critical minimum amount of ventilation air is biofiltered that we anticipate will result in maximum benefit in regards to odor and gas reduction. The original configuration of the deep-pit finisher modified for this research project is shown in Figure 2.

This original building consisted of two 300-hd feeder-to-finish rooms with an 8-ft deep-pit. The deep-pit was separated between rooms except for an equalizing channel at the bottom of the separation wall. Both rooms were identical in every way. The ventilation system consisted of 2-24" pit fans per room located at the pump-out locations. Sidewall curtains existed as well and these were controlled together, within each room, with a common curtain controller. To prepare this building for this research project, the west room was randomly selected to be the control room (Ctrl), with the east room as the biofiltered test room (BF). The fan modifications made to the east room are shown in Figure 3. The two existing pump-out locations were retained as fan plenums. The existing 24" pit fans were replaced with the following fans; 1-12" (fan 1), 1-16" (fan 2), 1-24" (fan 3), and 1-24" (fan 4), and distributed as shown in Figure 3. Each fan incorporated, available as standard agricultural ventilation fans, had the following specifications;

**Table 1.** Fan specifications for fans implemented in biofilter test barn. All fans from Multifan, Inc.

| | | CFM Delivery at Three Specific Operating Static Pressures | | |
|---|---|---|---|---|
| Fan | Model | 0.00 in wg | 0.05 in wg | 0.30 in wg |
| 1 | 4E30Q | 1,400 | 1,350 | 950 |
| 2 | 4E40Q | 3,100 | 2,950 | 2,000 |
| 3 | 6E63Q | 7,200 | 6,900 | 5,700 |
| 4 | 6E63Q | 7,200 | 6,900 | 5,700 |

The staging identified for these single-speed fans is given below with the estimated maximum airflow delivery at each stage and the estimated operating static pressures in series with the designed biofilter:

**Table 2.** Fan staging implemented in biofilter test barn with estimated total operating static pressure.

| | | Estimated | Total Stage Delivery | |
|---|---|---|---|---|
| Stage | Fans Operational | Static Pressure, in wc | CFM | CFM/space |
| 1 | 1 | 0.05 | 1,350 | 4.5 |
| 2 | 1 + 2 | 0.10 | 4,100 | 13.7 |
| 3 | 1 + 2 + 3 | 0.20 | 9,850 | 32.8 |
| 4 | 1 + 2 + 3 + 4 | 0.30 | 14,350 | 47.8 |

The desired maximum target ventilation rate was 45 cfm/space. At a space allowance of 8 $ft^2$/pig combined with an 8 ft ceiling results in an exchange rate *via* fans of 42 ACH. This level of biofiltered ventilation air is consistent with the trends shown and described with Figure 1.

*Biofilter Designs Used*

The Co-PIs on this research project have made significant contributions to biofilter design data for treating livestock ventilation air. Their contributions have resulted in clear guidelines for the design and expected operating characteristics for biofiltration. The information provided by these researchers (Nicolai *et al.*, 2002; Janni *et al.*, 2001; Nicolai and Janni, 2001) were used to guide the biofilter design for this research project. The biofilter designed was positioned as shown in Figure 4. The biofilter area

shown in Figure 4 was fitted with a biofilter that consisted of wood pallets that served as an air plenum with a mixture of compost and wood chips. This design was used and tested from June 2004 through October 2004. The basics of this design are given in Figures 5 to 7.

This biofilter design proved to be troublesome. The wood pallet plenum proved to be too restrictive on airflow and this, combined with excessive compaction issues associated with the compost-based media resulted in operating static pressures that were excessive, typically exceeding 0.50 in wg operating static pressure when at stage 4. It was decided in May 2005 to completely redesign the biofilter to avoid issues related to excessive operating static pressures.

The wood pallets used, and that have been typically used in other biofilters, were replaced with a series of 8 inch concrete blocks, with support rods, topped with hog panel and 1 inch fiberglass mesh. The revised plenum design is shown in Figures 8 to 10. The biofilter media was replaced with wood chips only, eliminating the compost material completely. The completed revised biofilter is shown in Figures 11 and 12. This second biofilter design drastically reduced the operating static pressure when at stage 4 and provided a stable and consistent air plenum from which to distribute the ventilation exhaust air.

B. Objective Two. To accommodate gas and odor emissions monitoring, a Mobile Emissions Laboratory (MEL) was placed on-site as shown in Figure 13. The MEL served as the on-site laboratory used to collect and control all data logging related to this research project. An inside picture of MEL is given in Figure 14. The control and test rooms along with the biofilter were sampled at the locations shown in Figure 15. The sample locations 1-5 are described below:

**Table 3.** Gas sampling locations and description thereof.

| | |
|---|---|
| Sample Location 1: | Pit Exhaust Air, test room |
| Sample Location 2: | Pit Exhaust Air, test room |
| Sample Location 3: | Control room |
| Sample Location 4: | Test Room |
| Sample Location 5: | Biofilter Exhaust Air |

Each sampling location was monitored for a total of 10-minutes, in sequence. The first seven minutes of monitoring were not used in the data analysis. This period of time was used to allow the gas analyzers to stabilize. The last 3-minutes of each 10-minute cycle were used in the data analysis. In addition to the five gas sampling locations, the following variables were measured and stored on a 1-minute basis.

**Table 4.** Auxiliary variables monitored for this research project.

Control room curtain position
Test room curtain position
Fan rpm (all six fans between both rooms)
Static pressure (fans, biofilter, both rooms)
Temperature (test room, control room, biofilter, outside air)
Wind speed
Wind direction
Solar intensity
Outside relative humidity

Odor samples were collected on roughly a bi-weekly basis throughout the monitoring period. Odor samples were collected in 10-liter Tedlar bags using the gas sampling system and locations shown in Figure 15. Odor samples were analyzed at the ISU Olfactometry Laboratory within 24 hours of collection.

C. Objective Three. The results of this research effort will be used to develop design guidelines for biofiltering the critical minimum ventilation air required to experience maximum benefit from biofiltration. These design guidelines will be given at the end of this report.

## VII. Research Findings: Gas and Odor Concentrations

This research project started in May 2004. Monitoring was conducted from May 2004 through October 2004 using the original biofilter design (Figures 5 to 7) consisting of a wood pallet plenum and a mixture of compost and wood chips. Several problems were encountered with this biofilter design in terms of compaction and excessive operating static pressure. Results related to this biofilter design will not be presented in this report. The biofilter was redesigned in June 2005 with monitoring conducted between June and October 2005 and between May and October 2006. The results collected in 2006 represent the best available results from this research project and thus it is the 2006 results that will be predominately presented in this research report. This project has been a learning experience and it essentially took the summers of 2004 and 2005 to "get it right". The results presented will cover key areas of concern for producers wanting to implement biofilters with their operation. These issues include; odor reduction, gas reduction, electrical energy usage, and overall biofilter design considerations. Results will predominantly be from the 2006 monitoring period although where appropriate 2005 results will be presented.

### A. Odor Results

Odor concentration data collected in 2005 and 2006 are given in Figure 16. These results compare the odor concentration (OU/ft$^3$) for the pit exhaust air (SL1) and the biofiltered exhaust air (SL5) (see Figure 14). The table below summarizes the findings for both 2005 and 2006.

**Table 5.** Overall odor reduction as a result of the installed biofilter (wood-chip only based filter).

| **Odor Results** | | | **SL 1** | **SL 5** |
|---|---|---|---|---|
| | Paired t-test | Ave % Reduction | Ave±SD | Ave±SD |
| 2005 Overall | 0.00017 | 44.2±25.4 | 696±638 | 397±461 |
| 2006 Overall | 0.00182 | 61.7±11.2 | 529±394 | 199±154 |

As shown in Table 5, the odor concentration results suggest a maximum average percent reduction of 61.7%. This level of odor reduction is on the low side of what has been reported in past biofilter research and it is believed to be the result of using wood chips-only as the scrubbing media. The control and test rooms (SLs 3 and 4, respectively) were found to be very similar in odor concentration as shown in Figure 16C for the 2006 results. These differences were not significantly different ($p>0.50$).

### B. Ammonia and Hydrogen Sulfide Concentration Results

Ammonia and hydrogen sulfide concentrations were measured at each of the five sampling locations given above. Unlike the odor measurements, a pseudo-continuous profile of these gases could be analyzed and investigated providing a better indication of biofilter performance. Figure 17 summarizes the ammonia concentration results for (A) the comparison between SLs 1 and 5 and (B) the comparison between room air (SLs 3 and 4). Similar plots for hydrogen sulfide are given in Figure 18. Tables 6A to 6C summarize the descriptive statistics for ammonia, hydrogen sulfide and carbon dioxide concentrations for the 2006 monitoring period.

The average ammonia concentration between the pit gas exhaust air (SL1) and post-biofiltration (SL5) was 9.5±3.3 ppm versus 2.6±3.0 ppm, respectively ($p<0.01$). This represents an overall reduction of 72.6%. For the Ctrl room air (SL3) and the BF room air (SL4) the ammonia concentrations were 4.2±2.6 ppm and 3.6±2.2 ppm, respectively ($p<0.01$).

**Table 6A.** Concentration of ammonia during the 2006 monitoring period.

| | Ammonia, ppm | | | |
|---|---|---|---|---|
| | **SL 1** | **SL 5** | **SL 3** | **SL 4** |
| **Average** | 9.5 | 2.6 | 4.2 | 3.6 |
| **Max** | 29.5 | 18.2 | 24.4 | 32.1 |
| **Min** | 0.6 | 0.1 | 0.5 | 0.0 |
| **SD** | 3.3 | 3.0 | 2.6 | 2.2 |
| **Median** | 9.6 | 1.1 | 3.4 | 3.1 |

The average hydrogen sulfide concentration between the pit gas exhaust air (SL1) and post-biofiltration (SL5) was 77±81 ppb versus 22±28 ppb, respectively ($p<0.01$). This represents an overall reduction of 71.4%. For the Ctrl room air (SL3) and the BF room air (SL4) the hydrogen sulfide concentrations were 51±68 ppb and 54±71 ppb, respectively ($p<0.05$).

**Table 6B.** Concentration of hydrogen sulfide during the 2006 monitoring period.

| | Hydrogen Sulfide, ppb | | | |
|---|---|---|---|---|
| | **SL 1** | **SL 5** | **SL 3** | **SL 4** |
| **Average** | 77 | 22 | 51 | 54 |
| **Max** | 1,518 | 747 | 2,824 | 1,260 |
| **Min** | 0 | 0 | 0 | 0 |
| **SD** | 81 | 28 | 68 | 71 |
| **Median** | 57 | 16 | 36 | 35 |

The average carbon dioxide concentration between the pit gas exhaust air (SL1) and post-biofiltration (SL5) was 936±314 ppm versus 947±306 ppm, respectively ($p<0.01$). This represents an overall increase of 1.2%. For the Ctrl room air (SL3) and the BF room air (SL4) the carbon dioxide concentrations were 743±343 ppm and 765±330 ppm, respectively ($p<0.01$). The carbon dioxide concentrations are given mainly to point out the differences between the pit gas air (SL1) and the post-biofiltration air (SL5). One of the concerns from this study was to make sure that the sampling system pulling air from the biofilter exhaust was in fact sampling the biofiltered air and not drawing surrounding ambient air into the sample line. These results give a clear indication that SL5 was in fact pulling air from the biofiltered exhaust stream. If this was not the case, the SL5 carbon dioxide concentrations would have been closer to ambient air conditions (approx. 345 ppm).

**Table 6C.** Concentration of carbon dioxide during the 2006 monitoring period.

| | Carbon Dioxide, ppm | | | |
|---|---|---|---|---|
| | **SL 1** | **SL 5** | **SL 3** | **SL 4** |
| **Average** | 936 | 947 | 743 | 765 |
| **Max** | 2,125 | 2,097 | 2,087 | 2,077 |
| **Min** | 331 | 394 | 325 | 338 |
| **SD** | 314 | 306 | 343 | 330 |
| **Median** | 915 | 920 | 624 | 683 |

## VIII. Research Findings: Gas and Odor Emission

The previous analysis highlighted the behavior of odor and gas concentrations from the biofilter developed for this research project. Concentration by itself without the inclusion of ventilation rate is not meaningful when issues related to atmospheric emission are addressed. Therefore, it is the emissions data that proves to be most beneficial when dealing with issues off-site from a swine source. In order to address the impact of biofiltration on odor and gas emissions, an assessment of real-time ventilation rate was required.

The control and test rooms monitored for this research project posed a challenge in that the majority of hot-weather ventilation was delivered naturally by lowering sidewall curtains and relying on wind effects to ventilate the building. This strategy serves the swine industry very well but it poses a challenge for emissions research since the prediction of ventilation rate in a naturally ventilated building is difficult. To estimate the ventilation rate delivered to both the control and test rooms, the fan ventilation rate was added to the predicted wind-driven ventilation rate using wind speed, wind direction, and curtain opening level. The total ventilation rate was then estimated as follows:

$$V_{total} = V_{fans} + V_{curtain}$$

The ventilation rate delivered by the fans was estimated using 85% of the reported ventilation rate at any given operating static pressure. A linear equation was fitted to each reported fan curve for the fans identified in Table 1. A typical result is shown in Figure 19. The ventilation rate delivered through the curtains was estimated using the curtain opening size at the windward vent multiplied by the wind speed and corrected for impaction angle (ie. wind direction) on the curtain. The correction factor has been called the effectiveness, E (Albright, 1990). Using this concept, the estimated airflow through the barn with curtains as affected by wind was calculated as;

$$V_{curtain} = E\,(h/12)\,L\,V_{wind}\,(5280/60)$$

Where

$V_{curtain}$ = wind driven ventilation rate, cfm.
E = effectiveness (dimensionless)
h = windward side curtain opening, inches
L = curtain length (=57.5 ft)
$V_{wind}$ = wind speed, miles/hr

The effectiveness E is an attempt to take into account wind direction acting on the windward curtain and overall inefficiencies in forcing air through an opening such as a barn sidewall. The recommended values for E range from 0.5 to 0.6 for perpendicular winds and from 0.25 to 0.35 for diagonal winds. These values assume that the opening subjected to wind is an opening with no obstructions. For this research project, the incorporated E values were lowered to account for framing members and bird screen present in curtain sided barns, both adding to the inefficiencies of sidewall curtains in delivering airflow *via* wind. The resulting effectiveness E used for this research project as a function of impaction angle is given in Figure 20.

For example, take the situation shown in Figure 21. If the wind direction, as determined by the on-site weather station, was recorded as 150 degrees as shown, with the south-side curtain open 25 inches and subjected to a 13 mph wind, the estimated effectiveness E was;

$$E = 4 \times 10^{-5}\,(150)^2 - 0.0063\,(150) + 0.3529$$
$$= 0.31$$

Resulting in an estimated airflow rate as delivered by this wind potential as;

$$V_{curtain} = (0.31)\,(25/12\text{ ft})\,(57.5\text{ ft})\,(13\text{ miles/hr})\,(5280\text{ ft/mile})\,(1\text{ hr}/60\text{ minutes})$$
$$= 42{,}483\text{ cfm } (142\text{ cfm/pig})$$

It should be noted that the south and north side curtains in each room were controlled with the same curtain machine and therefore their openings were the same. If the windward curtain was open with the leeward curtain closed, the effectiveness E would need to be lowered further yet from the values estimated above.

It should be made very clear that the effectiveness method incorporated with this research project provided a reasonable method to compare the biofiltered and control barns in this side-by-side situation. Any errors using this method were applied to both rooms in the same manner. The absolute value of the emission results presented in this report *can not be used to quantify the emissions for regulatory purposes*. The method used for estimating wind-driven ventilation in curtain sided barns is still an unsettled issue with the research community and thus the method used here has not been declared an acceptable approach for quantifying actual emissions. Nevertheless, the comparison in this side-by-side test to estimate reduction potentials was deemed appropriate.

A. Odor Emission

The odor concentration data presented earlier was combined with the calculated total room ventilation rate to estimate the odor emission. The governing relation used was;

$$OU/min = ODT\ (V_{total})$$

Where

ODT = odor concentration, $OU/ft^3$

Figure 22 summarizes the odor emission results for the 2006 data set. The data presented includes the specific odor sampling times along with the cumulative results for the BF and Ctrl barns (Figure 22A). In total, the cumulative difference indicated an overall odor emission reduction of 23.1%. When a reduced odor emission was measured (ie. positive effect), the average percent reduction was 39.8%. The odor reductions ranged from a low of -14% to a high of 74.1% as shown in Figure 22B. Initially, and as shown in Figure 22, the odor emission differences were drastic with the test barn 15-74% lower in odor emission compared to the control room. The odor emission results for the measurements conducted on 8/11, 8/30 and 9/27 lowered the overall performance statistics of the biofilter in odor emission reduction. It is unclear why the odor emission results coalesced for these three particular measurements.

B. Ammonia Emission

The ammonia emission results for the 2006 monitoring period are given in Table 7 and Figures 23 and 24. Figure 24 highlights the ammonia emission in g/AU-day for the pit fans and the curtain sidewalls for both the test and control rooms. One animal unit (AU) is equivalent to 1,100 lbs. Figure 24B summarizes the cumulative ammonia emission results throughout the entire 2006 monitoring period. Based on the daily averages, the BF barn averaged 39.6±35.4 g/AU-day of ammonia emission with the Ctrl barn averaging 93.5±43.4 g/AU-day. Based on these averages, the BF barn experienced a reduction in ammonia emission of 57.6%.

Also given in Table 7 are the emissions on a kg/day and g/pig-day basis. Emission data is often presented in this manner. One of the parameters of interest in emission data is the number of animals required, for a given production system, to exceed the CIRCLA and EPCRA reporting requirements of 100 lb/day. For the kg/day data, the maximum daily ammonia emission was 4.7 kg/day for the BF room and 5.4 kg/day for the Ctrl room. These values result in 10.3 lb/day and 11.9 lb/day, respectively. These values both correspond to rooms with 300 pig capacity, and therefore result in 0.034 lb/pig-day and 0.040 lb/pig-day, respectively. These results imply that to exceed 100 lb NH3/day, the pig capacity would need to be 2,941 and 2,500 pigs, for the BF and Ctrl rooms, respectively. In previous research conducted for the USDA on deep-pit swine finishers, a pig capacity of roughly 2,400 pigs was cited as the number that would trigger at least one daily average exceedance of the 100 lb/day reporting limit.

**Table 7.** Ammonia emission data estimates for the BF and Ctrl rooms for the 2006 monitoring period.

| | **g/AU-day** | **kg/day** | **g/pig-day** |
|---|---|---|---|
| BF Room | 39.6±35.4 | 1.5±1.0 | 5.1±3.4 |
| Ctrl Room | 93.5±43.4 | 3.3±0.8 | 11.1±2.8 |
| % Reduction | 57.6 | 54.5 | 54.0 |

C. Hydrogen Sulfide Emission

The hydrogen sulfide emission results for the 2006 monitoring period are given in Figures 25 and 26. Figure 25 highlights the hydrogen sulfide emission in g/AU-day for the pit fans and the curtain sidewalls for both the biofilter and control barns. Figure 26B summarizes the cumulative hydrogen sulfide emission results throughout the entire 2006 monitoring period. Based on the daily averages, the BF barn averaged 0.9±0.6 g/AU-day of hydrogen sulfide emission with the Ctrl barn averaging 2.0±1.4 g/AU-day. Based on these averages, the BF barn experienced a reduction in hydrogen sulfide emission of 53.0%.

**Table 8.** Hydrogen sulfide emission data estimates for the BF and Ctrl rooms for the 2006 monitoring period.

| | **g/AU-day** | **kg/day** | **g/pig-day** |
|---|---|---|---|
| BF Room | 0.9±0.6 | 0.036±0.020 | 0.12±0.07 |
| Ctrl Room | 2.0±1.4 | 0.065±0.029 | 0.22±0.10 |
| % Reduction | 53.0 | 45.0 | 44.5 |

## IX. Research Findings: Specifics Related to Emissions

Curtain-sided swine facilities are very common housing systems. Since these facilities provide an uncontrolled ventilation emission source when the curtains are opened, biofiltration of this air is not an option. The results presented in this research project indicate that deep-pit curtain-sided housing systems can be modified in a way that results in a significant decrease in gas and odor emissions. The strategy, as defined previously, was to size the fan ventilation portion of the ventilation process high enough that curtain sided operation was minimized to hot weather daytime periods, with fan ventilation predominately occurring during those times of the day when the atmosphere is likely to be most stable.

A. Fan Airflow as a Percentage of Total Airflow

Figure 27 shows a typical 6-day curtain control response between the biofiler (BF) and control (Ctrl) barns in response to outdoor temperature. For the entire month of July 2006, the BF barn curtains were open no more than 1/3$^{rd}$ of the way (15 inches) for 24.3% of the time. During this same period, the Ctrl barn curtains were open no more than 1/3$^{rd}$ of the way for 5.0% of the time. If one considers the time in July where the atmosphere has the best chance of being stable, defined here as the period between 8pm and 7am of the following morning, the BF barn curtains were open no more than 1/3$^{rd}$ of the way for 39.3% of the time. In comparison, the Ctrl barn curtains were no more than 1/3$^{rd}$ of the way for 9.4% of the time between the hours of 8pm and 7am of the following morning. These differences are crucial as they define the potential difference in biofiltration *via* fans versus uncontrolled emissions *via* curtains. The difference in curtain response was a function of the BF barn fans sized at a level of about 48 cfm/space with the Ctrl barn fan system sized 38 cfm/space.

Both barns were being ventilated at similar levels throughout the study, as predicted with the fan and curtain ventilation rate procedures specified. For the same 6-day period as shown in Figure 27, a comparison of the predicted total ventilation rate between barns is shown in Figure 28. In terms of overall percentages, the BF barn fan percentage of the total over this 6-day period was 58.2±20.2% and the Ctrl barn fan percentage of the total was 45.3±19.2% as shown in Figure 29. For the entire month of July 2006, the BF fan percentage was 58.8±24.8% with the Ctrl barn fan percentage of the total at 46.1±21.1%.

Of greater importance however is the percentage of fan airflow between barns during the most stable portion of the atmosphere. If one considers the time period between 8pm and 7am of each day, the percentage of total airflow delivered by fans during this period was 67% for the BF room and 49% for the Ctrl room for the entire month of July 2006. This implies that on average 67% of the total emitted air from the BF room was being scrubbed by the biofilter during the potentially most stable periods of the day. Figure 30 shows the fan percentage of the total airflow between the BF and Ctrl barns for those periods between 8pm and 7am. Clearly, the BF barn was utilizing fans for the majority of night ventilation and therefore this exhaust air was being treated by the biofilter.

Figure 31 represents a histogram of the BF versus Ctrl room fan percentage of the total airflow for the entire month of July 2006. Clearly, the Ctrl room fan percentage of total was centered in the 30-50% range where the BF fan percentage of total was in the 55-100% range.

B. Influence of Water Cycling

The moisture content of biofilters is a critical variable to achieve desired reduction efficiencies. The cycling schedule used for the vast majority of the monitoring periods shown was to operate a sprinkling schedule in two-1 hour cycling routines, one between 0600-0700 and the other between 2100-2200 hrs of each day. As a test of this cycling schedule, there was a period where the cycling was cut in half, allowing cycling between 0600-0630 and 2100-2130. This proceeded from September 1 through September 7, 2006. The response in ammonia emission during this time is shown in Figure 32. A rather dramatic increase in ammonia emission occurred during this reduced cycling period, in a manner that follows the changes in watering patterns quite dramatically.

## X. Energy Consumption

Mitigation strategies all have costs associated with them. Producers need to be aware of these costs when formulating an odor and gas reduction plan. The biofilter research presented in this study was monitored for electrical energy usage to provide producers with a good estimate of the operational costs associated with this biofiltration strategy. The table below gives an estimate of the operational costs associated with biofiltration.

**Table 9.** Fan operation costs associated with biofiltration.

| | Biofilter Barn | | | Ctrl Barn | | |
|---|---|---|---|---|---|---|
| Month 2006 | Total kw-hrs | Days | $/day-space | Total kw-hrs | Days | $/day-space |
| June | 615.3 | 22.1 | $0.0074 | 285.9 | 22.1 | $0.0034 |
| July | 1046.7 | 31 | $0.0090 | 400.3 | 31 | $0.0034 |
| August | 1109.5 | 31 | $0.0095 | 400.3 | 31 | $0.0034 |
| September | 1074.7 | 31 | $0.0096 | 387.4 | 31 | $0.0034 |
| October | 548.2 | 22.4 | $0.0065 | 289.2 | 22.4 | $0.0034 |

The cost differentials associated with biofiltration were the combined influence of a higher fan capacity delivered to the biofilter barn and a progressively increasing operating static pressure as the biofilter fans staged progressively on. The maximum cost differential for biofiltration occurred during September 2006 where the differential cost compared to the control barn was $0.0062/day-space. If one assumes that this excess biofiltration cost occurs for a maximum period of 150 days, then the projected cost of biofiltration for a 300-hd finisher would be $279. This cost, on an annual basis, would be partitioned into 2.2 turns at 300 pigs/turn or a total of 660 pigs resulting in a total averaged per pig cost of biofiltration of $0.42/pig.

## XI. Partial Biofiltration Design Considerations

Based on the experiences from this research project, specific biofilter design recommendations can be established. These recommendations are intended to supplement biofilter design

recommendations that have been given over the years from Co-PIs Nicolai, Janni, Schmidt, and Jacobson. The biofilter design recommendations are given below:

1. Biofilter Media: Very careful attention to biofilter media composition needs to occur. If a mixture of media is composed with compost material, the fraction of compost needs to adhere strictly to the recommendations given in past documents on biofilter design. Nicolai et al (2001) provides an excellent design recommendation guideline for the addition of compost to wood chips serving as a biofilter media and the resulting static pressures that one can expect. This research project showed however that a biofilter consisting strictly of wood chips is an effective media for biofiltration and one that results in operating static pressures that work well with typical agricultural fans already in use.

2. Biofilter Fan Selection: Biofilter design considerations should be based on the use of existing agricultural-use fans. Fan selection and biofilter design operating static pressures need to be closely matched. The recommendation is that fans used for the biofiltration process should be single-speed fans and staged accordingly. Variable speed fans have poor operating pressure characteristics when operated at low variable speed settings. Single-speed fans will eliminate this as a possibility.

3. Biofilter Plenum Design: It has been a common practice to use stacked wood-pallets for constructing the plenum in horizontal biofilters. Our experience with this approach for this research project was not favorable. The modified plenum using concrete blocks, galvanized support bars, hog panel, and mesh proved to be an excellent plenum that served this research project well, providing a trouble-free biofilter plenum design. The recommendation is to avoid wood pallets all together and use a method similar to the final design tested in this research project.

4. Biofilter Fan Transition: It is extremely important that the transition area from the fan to the biofilter plenum be designed in such a manner that an easy and restriction-free zone exists into the biofilter. The transition area that was designed in the second generation biofilter for this research project used a transition area criteria of 500 cfm/ft$^2$. This proved to be a very acceptable transition area for design purposes. The recommendation would be to maintain this transition area at or below 500 cfm/ft$^2$ for all locations prior to the biofilter plenum. The diagram shown below is an example of a transition area designed. This transition area served two fans with a total capacity of approximately 7,700 cfm. The total face-area of this plenum that distributed air to the biofilter plenum was 14.2 ft$^2$, resulting in a transition area restriction of 543 cfm/ft$^2$ (7,700 cfm/14 ft$^2$). It is extremely important that this guideline be adhered to as closely as possible. Failure to provide a restriction-free distribution area into the biofilter plenum will most certainly result in excessive operating static pressures which will in turn result in excessive operating costs.

5. Water Cycling: Biofilter moisture content is a critical parameter as has been reported elsewhere. Our experience with this research supports this fact. An improvement to the approach used for this research project in an attempt to conserve water-use, would be to install a biofilter media moisture sensor that can be used to control the water addition rates to the media. The approach used for this research project used a fixed cycling pattern based on experience. However, this resulted in excessive water use as no credit was given to natural rainfall on the media or periods where low evaporation rates were occurring. It is clear however that a plan to keep the biofilter media moist is crucial to the success of the biofilter.

6. Partial Biofiltration: The results from this research support the concept of partial biofiltration. The research data collected for this project demonstrated that a significant portion of the evening hours was fan ventilated and scrubbed *via* biofiltration at a maximum biofilter fan rate of 48 cfm/pig. This rate is roughly 50% of the total fan capacity designed in swine finishing facilities. The benefits of this approach we believe warrant further investigation. This strategy is expected to have a greater impact for the majority of swine finishing facilities designed today than has been demonstrated in this research project. The reasoning for this is that most all curtain-sided swine finishing facilities today size the fan-ventilation portion of the ventilation process to a level that rarely exceeds 30 cfm/pig. The control barn used for this research project was sized for fan ventilation at about 38 cfm/pig. This added 8 cfm/pig fan capacity in the control barn narrowed the actual benefit of partial biofiltration shown with this research project. In other words, with the control barn at 38 cfm/pig versus a more customary 30 cfm/pig and lower fan capacity, the curtains were used less in this control barn versus most curtain-sided barns in use today.

7. Barn Modifications: Fans selected for biofiltration should be selected as single-speed fans. It is felt that better control and fan performance will be realized with single-speed fans versus variable speed fans. Multiple fans staged in a single-speed arrangement will result in better long-term performance. In addition, it is extremely important that secondary inlets into the attic space and primary inlets into the room space be sized to design specifications to avoid excessive operating static pressure. With the added restriction of a biofilter, the ventilation system needs to minimize all other air restriction points in the ventilation process. Ultimately, the biofilter installed can not negatively affect the ventilation needs of the animals. The diagram below shows an added gable-vent that was installed for this research project to avoid excessive operating pressures into the attic space. Unfortunately, many barns today are built with a lack of attic venting that results in excessive operating pressures for the fans. With a biofilter installed, it is very important that no other points in the ventilation process add to the operating static pressure for the fans.

## X. Project Summary

A summary of the results for the 2006 monitoring period from this research project are listed below for the biofilter (BF) test room and the control (Ctrl) room:

| | Room Air | | Fan Exhaust Air | | |
|---|---|---|---|---|---|
| | BF | Ctrl | BF | Ctrl | % Reduction |
| Odor Concentration | | | | | |
| ($OU/ft^3$) | 517±463 | 488±345 | 199±154 | 529±394 | 61.7% |
| NH3 Concentration | | | | | |
| (ppm) | 3.6±2.2 | 4.2±2.6 | 2.6±3.0 | 9.5±3.3 | 72.6% |
| H2S Concentration | | | | | |
| (ppb) | 54±71 | 51±68 | 22±28 | 77±81 | 71.4% |
| Odor Emission | | | | | |
| (OU/min, ave) | $5.1x10^6$ | $6.6x10^6$ | | | 22.7% |
| (OU/min, SD) | $4.6x10^6$ | $4.0x10^6$ | | | |
| NH3 Emission | | | | | |
| (g/AU-day) | 39.6±35.4 | 93.5±43.4 | | | 57.6% |
| (kg/day) | 1.5±1.0 | 3.3±0.8 | | | 54.5% |
| (g/pig-day) | 5.1±3.4 | 11.1±2.8 | | | 54.0% |
| H2S Emission | | | | | |
| (g/AU-day) | 0.9±0.6 | 2.0±1.4 | | | 53.0% |
| (kg/day) | 0.036±0.020 | 0.065±0.029 | | | 45.0% |
| (g/pig-day) | 0.12±0.07 | 0.22±0.10 | | | 44.5% |
| Energy Consumption | | | | | |
| ($/day-space) | $0.0084 | $0.0034 | | | 47.1% increase |

## XII. References


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6. Nicolai, R.E., Janni, K.A. and D.R. Schmidt. 2002. Biofilter design information. http://www.bae.umn.edu/extens/aeu/baeu18.html

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8. Nicolai, R.E. and K.A. Janni. 2001. Determining pressure drop through compost-woodchip biofilter media. ASAE Paper No. 014080. ASAE, St. Joseph, MI 49085.
9. Alibright, L.D. 1990. Environment Control for Animals and Plants. The American Society of Agricultural Engineers Publishers, St. Joseph, MI. pp 337-338.

## XIII. Acknowledgements

The PI would like to thank Mr. Greg Carlson, Stratford Iowa, for allowing this research project to be conducted at his production site. We were given ready-access to the site which made for an enjoyable and productive research project. Cooperators like Greg make this research possible ultimately allowing research results to be readily available for the producer. We had many valuable conversations with Greg that stimulated many productive changes to this research project. The PI would like to thank Brian Zelle, Michael Crevalt, David Smith, and Aaron Smith for the many hours of design changes and site inspections required to make this research project possible. Most importantly, the PI would like to thank the Iowa Pork Producers Association for making this research project possible with their generous funding support.

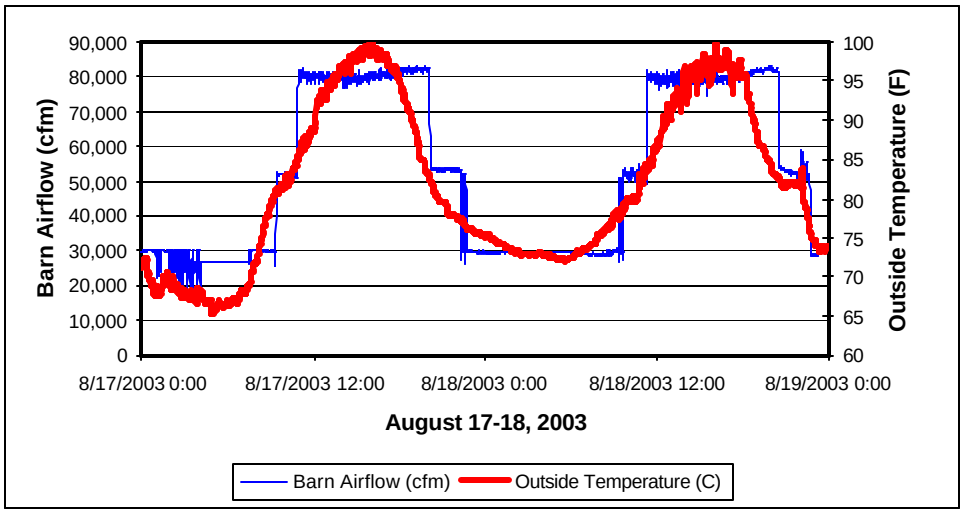



**Figure 1.** Building airflow changes with summer outside temperature.

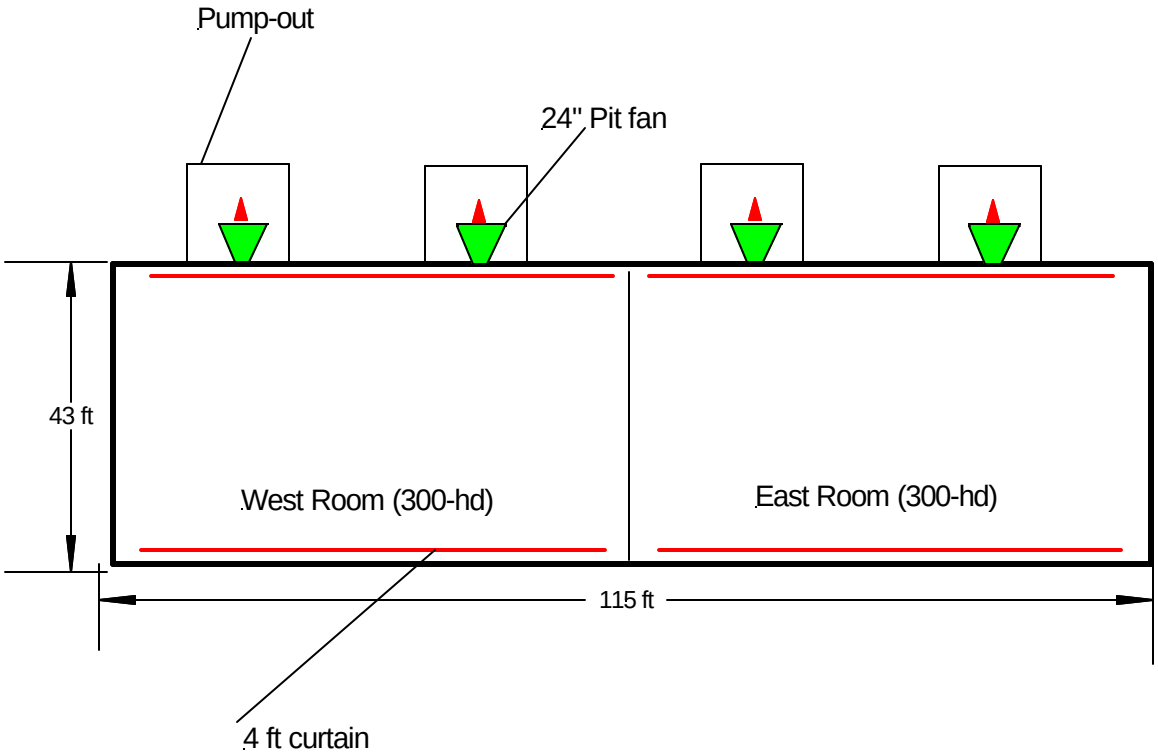



**Figure 2.** Building layout prior to modifications.

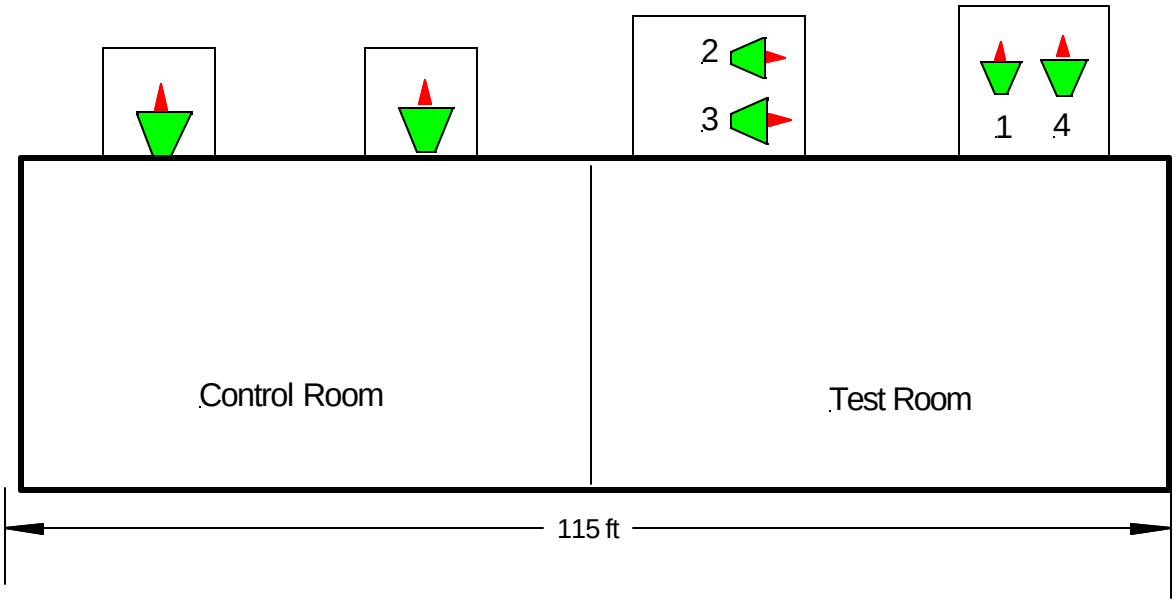



**Figure 3.** Building layout after fan modifications.

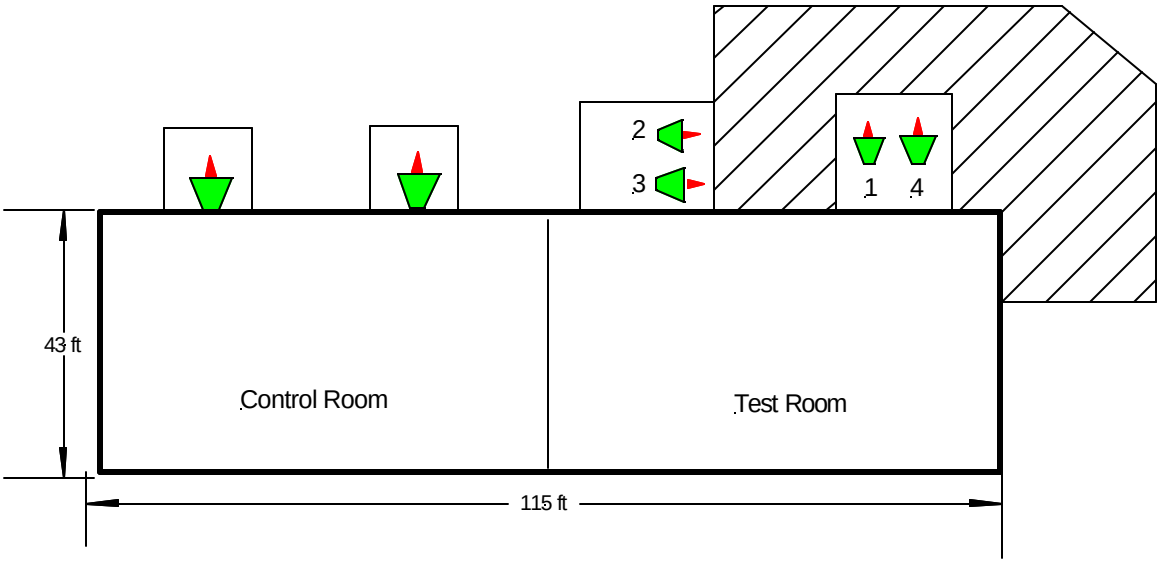



**Figure 4.** General layout of the installed biofilter.

**Figure 5.** Original biofilter set-up using pallets and a mixture of compost/wood chips.

**Figure 6.** Fan plenums installed for distribution to the pallet floor system.

**Figure 7.** Final biofilter layout with original pallet distribution system and compost/wood chips media.

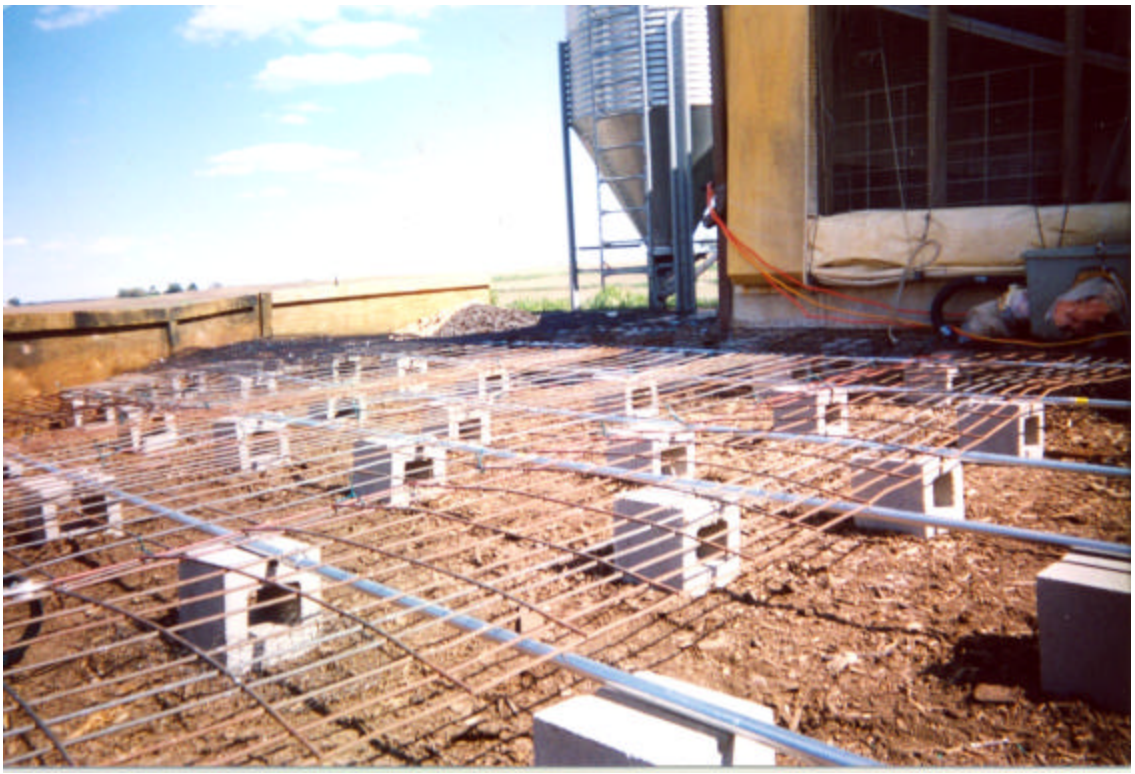


**Figure 8.** Revised biofilter plenum layout with 8” blocks, electrical conduit, and hog panel.

**Figure 9.** Revised biofilter plenum layout with 8” blocks, electrical conduit, and hog panel.

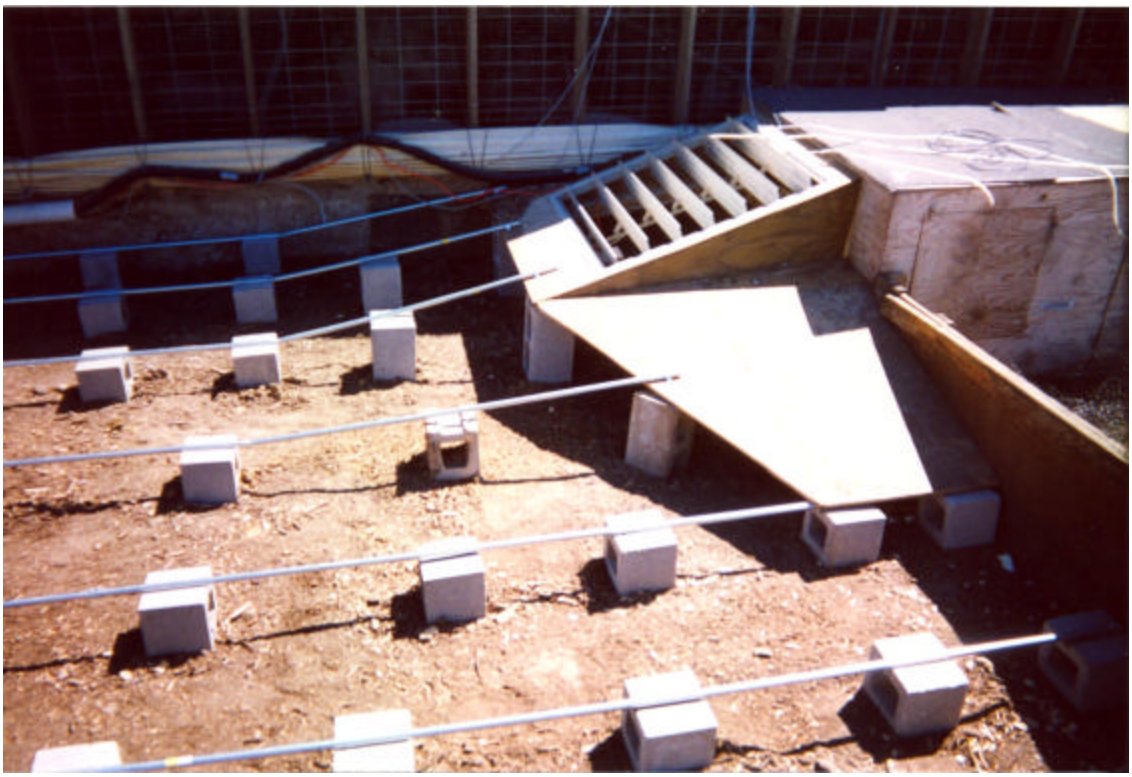


**Figure 10.** Revised biofilter fan plenum layout into floor distribution area.

**Figure 11.** Mesh (1”x1”) applied over hog panel with wood chips-only serving as the biofilter media.

**Figure 12.** Completed view of the revised biofilter.


**Figure 13.** View of the Mobile Emissions Laboratory.

**Figure 14.** Inside view of the Mobile Emissions Laboratory.

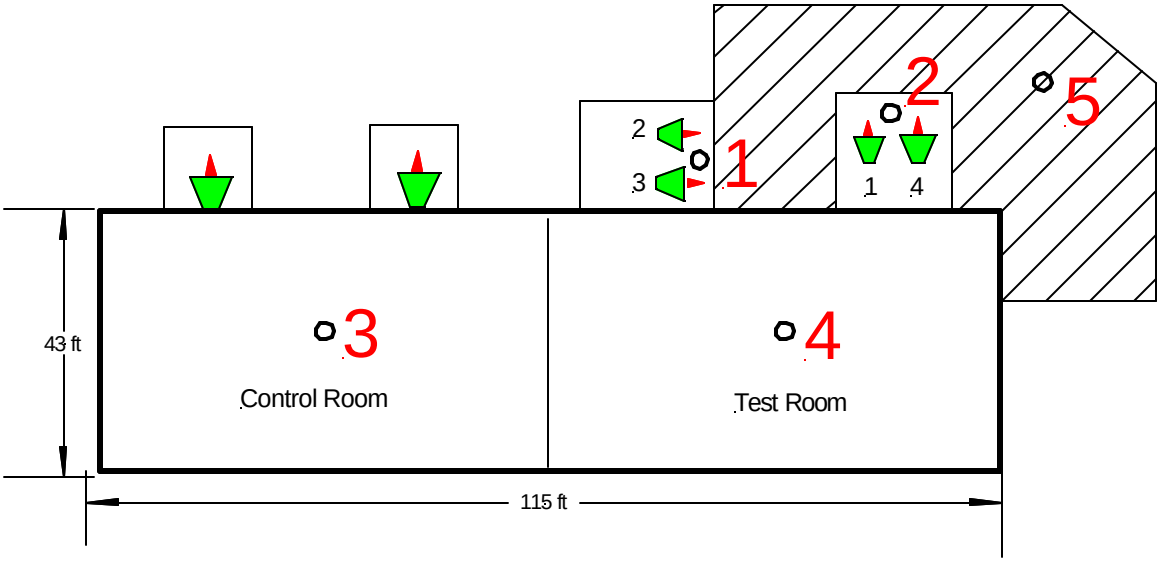
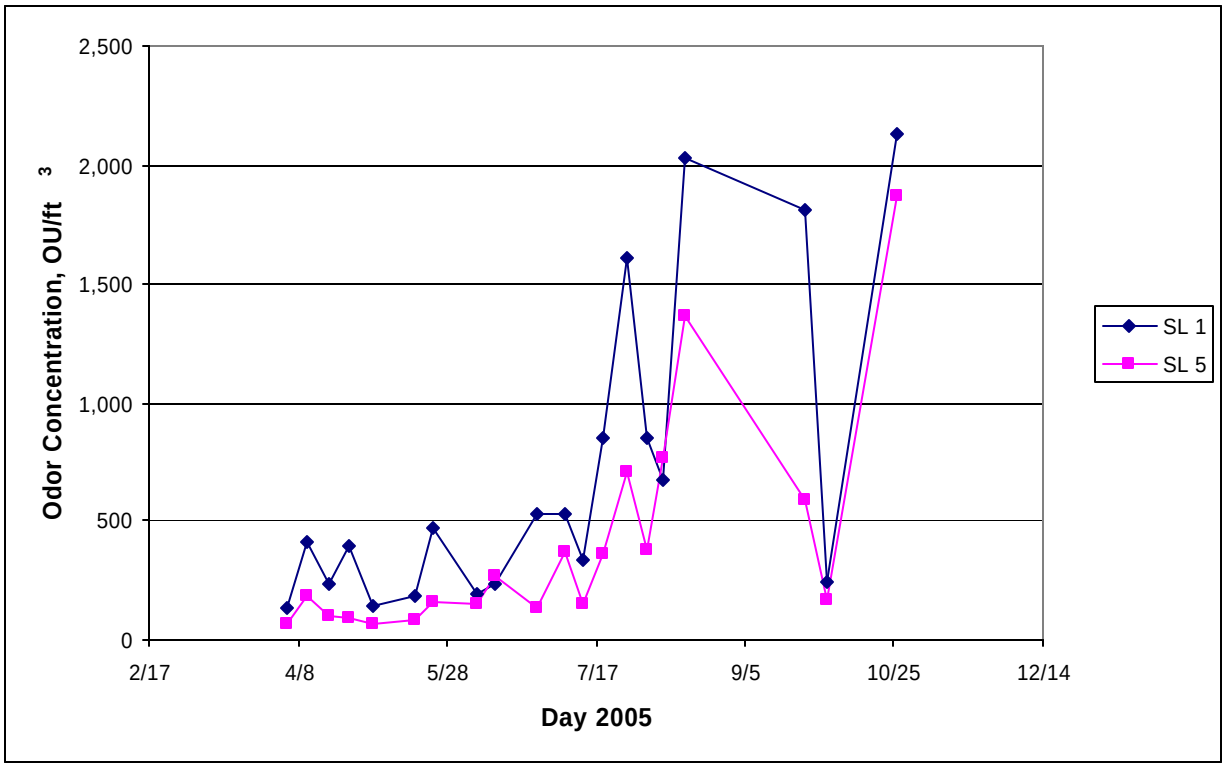



**Figure 15.** Biofilter gas sampling locations.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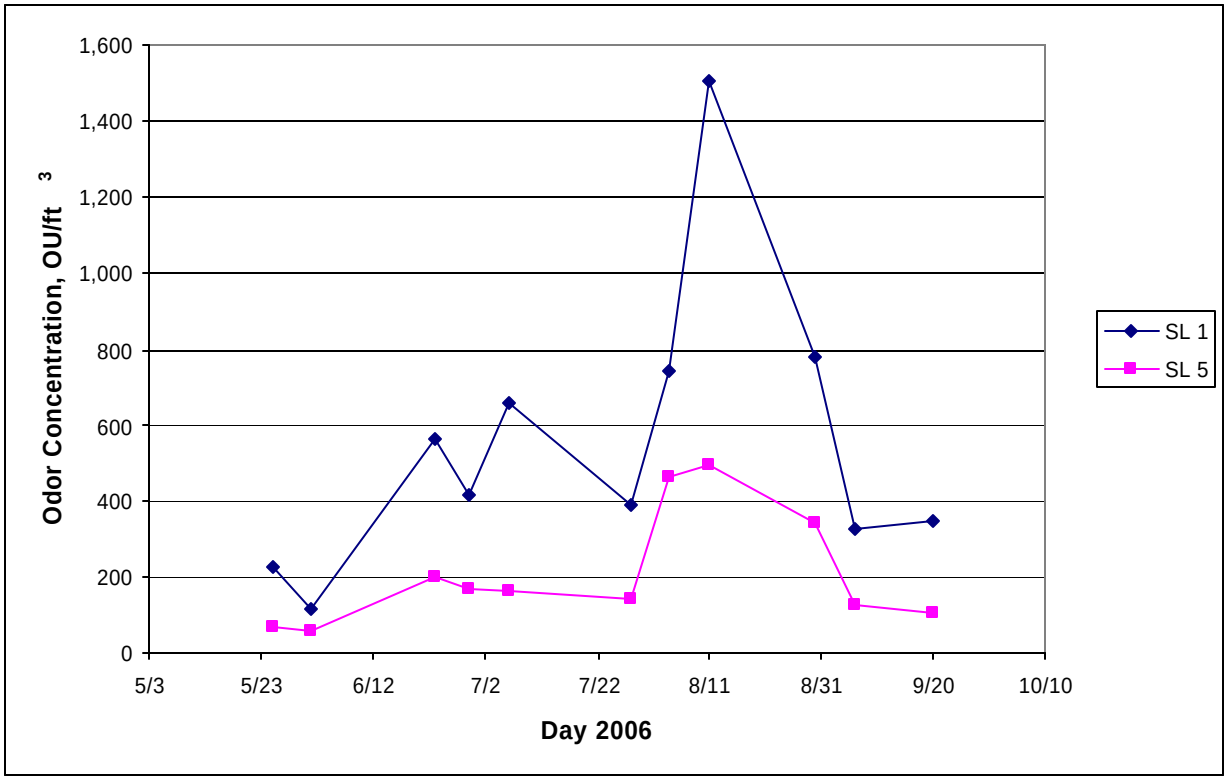
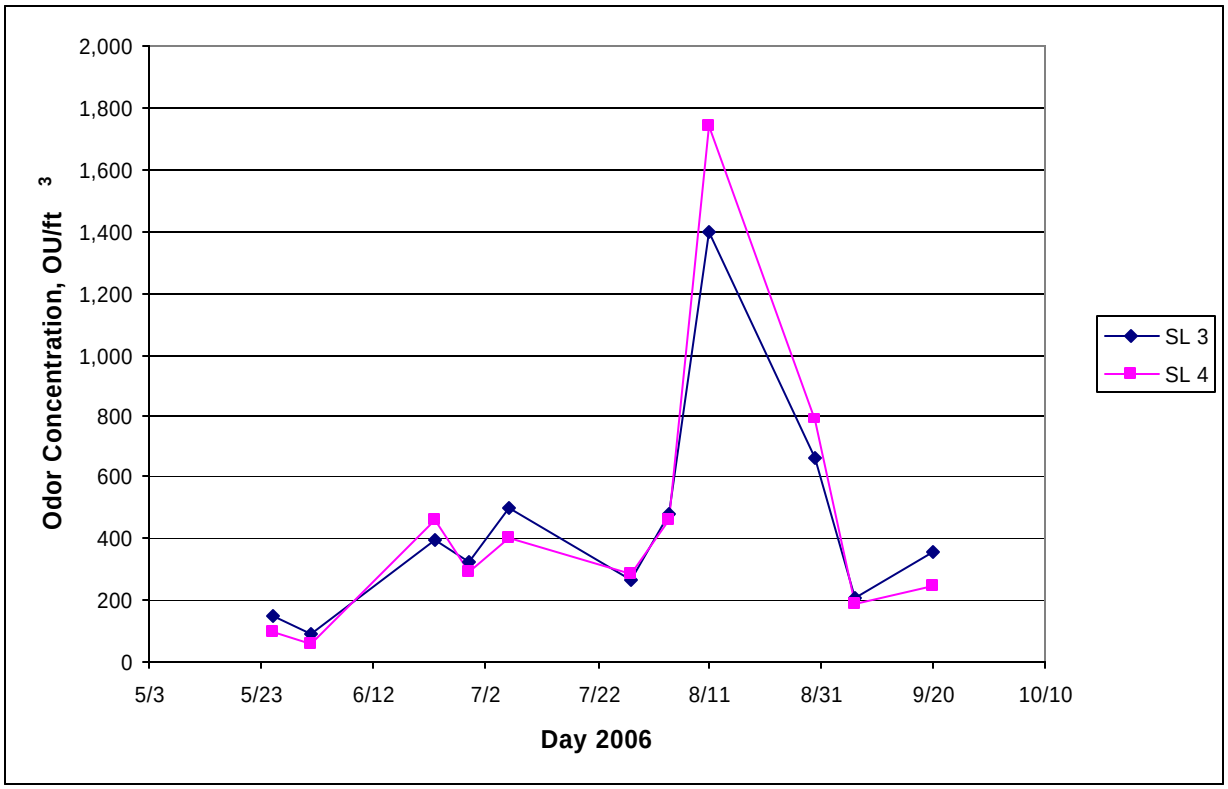
2,000
1,500
1,000
500
0
Odor Concentration, OU/ft 3
2/17
4/8
5/28
7/17
9/5
10/25
12/14
Day 2005
SL 1
SL 5

**A**

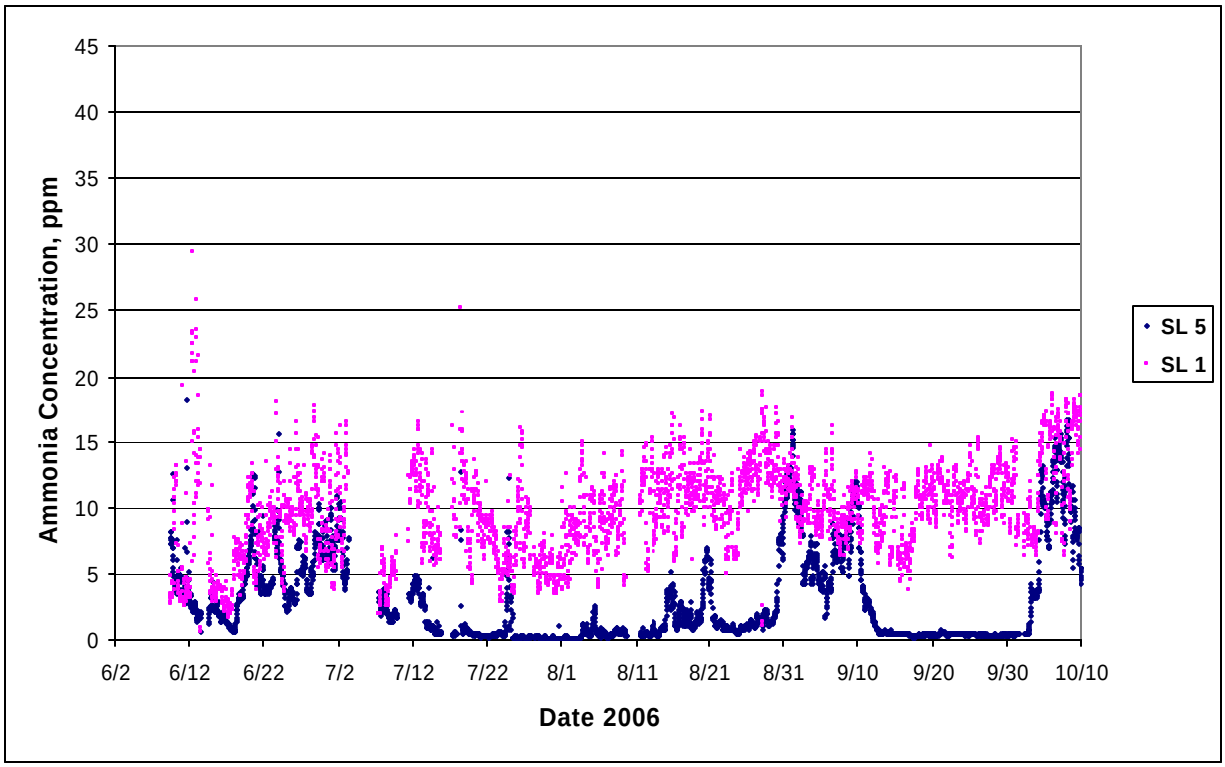

1,600
1,400
1,200
1,000
800
600
400
200
0
Odor Concentration, OU/ft 3
5/3
5/23
6/12
7/2
7/22
8/11
8/31
9/20
10/10
Day 2006
SL 1
SL 5

**B**

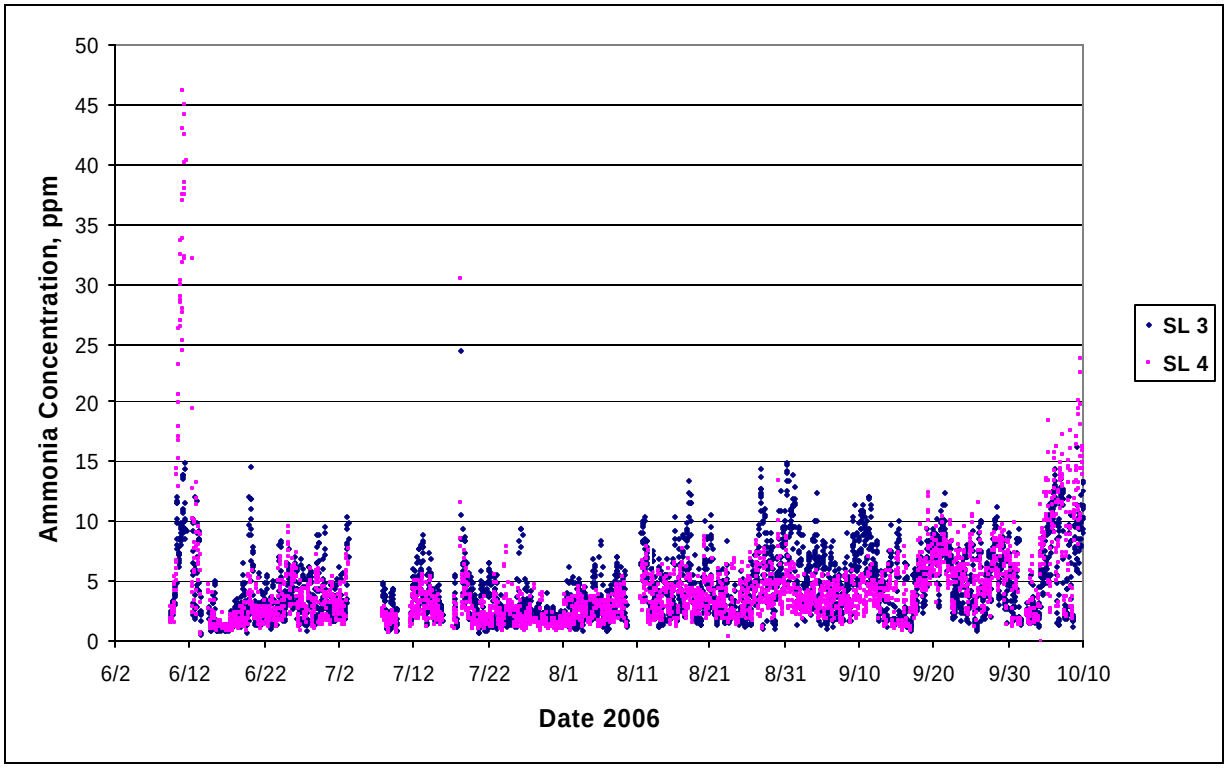



**C**

**Figure 16.** Odor concentration profiles for SLs 1 and 5 for (A) 2005 and (B) 2006 and a comparison between room air odor concentrations for (C) 2006 (SL3=Ctrl room, SL4=BF room).

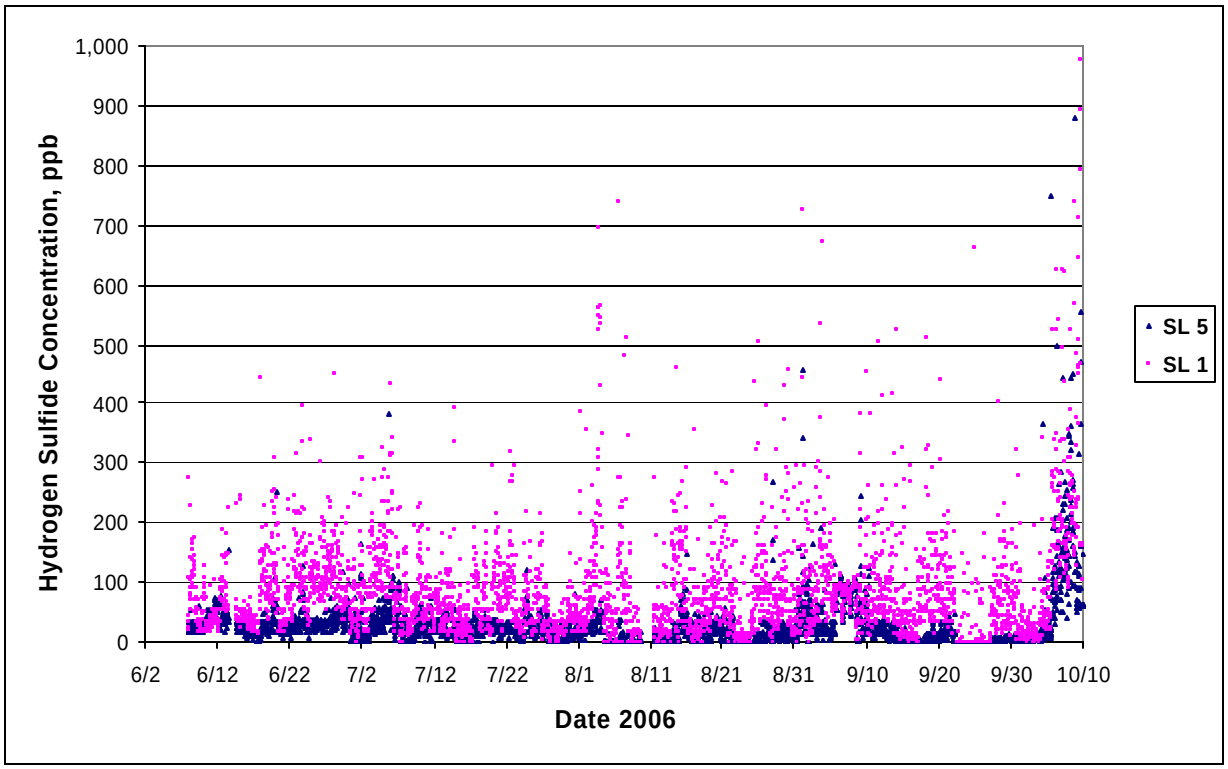



A

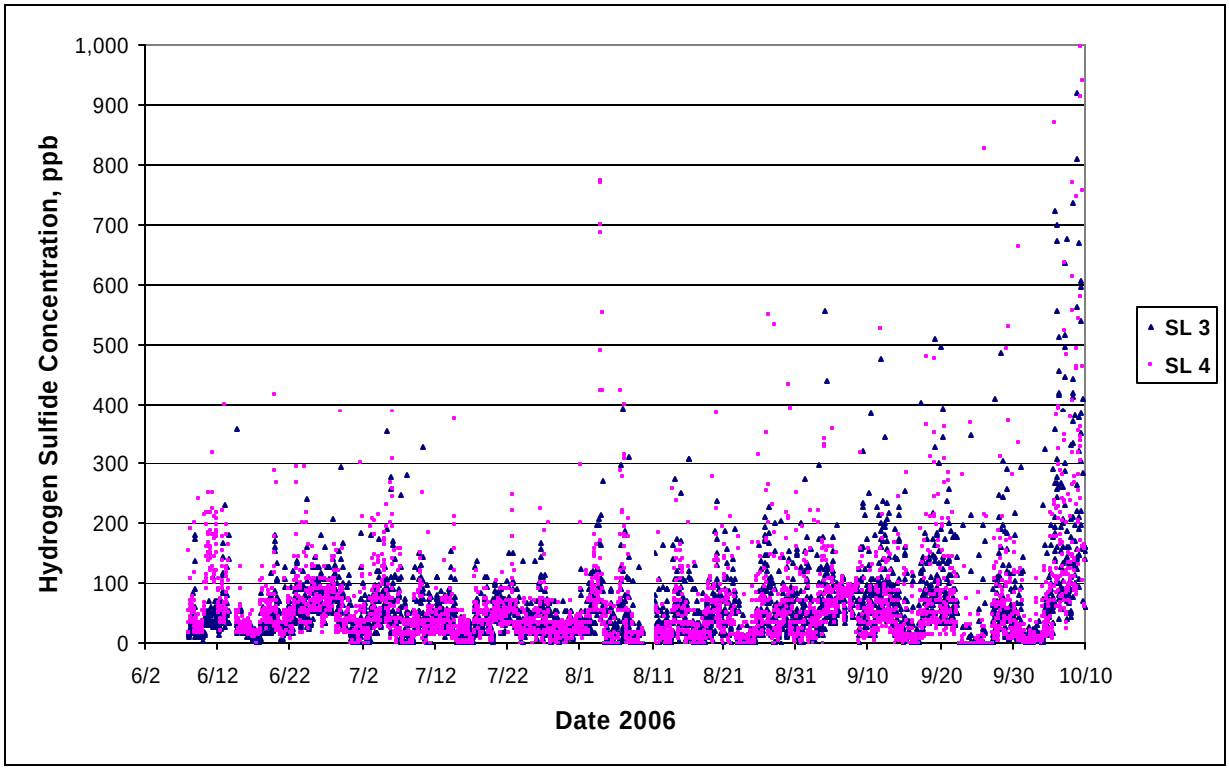



B

**Figure 17.** NH3 concentration profiles during 2006 for (A) SLs 1 and 5 and (B) SLs 3 and 4.




**A**




**B**

**Figure 18.** H2S concentration profiles during 2006 for (A) SLs 1 and 5 and (B) SLs 3 and 4.

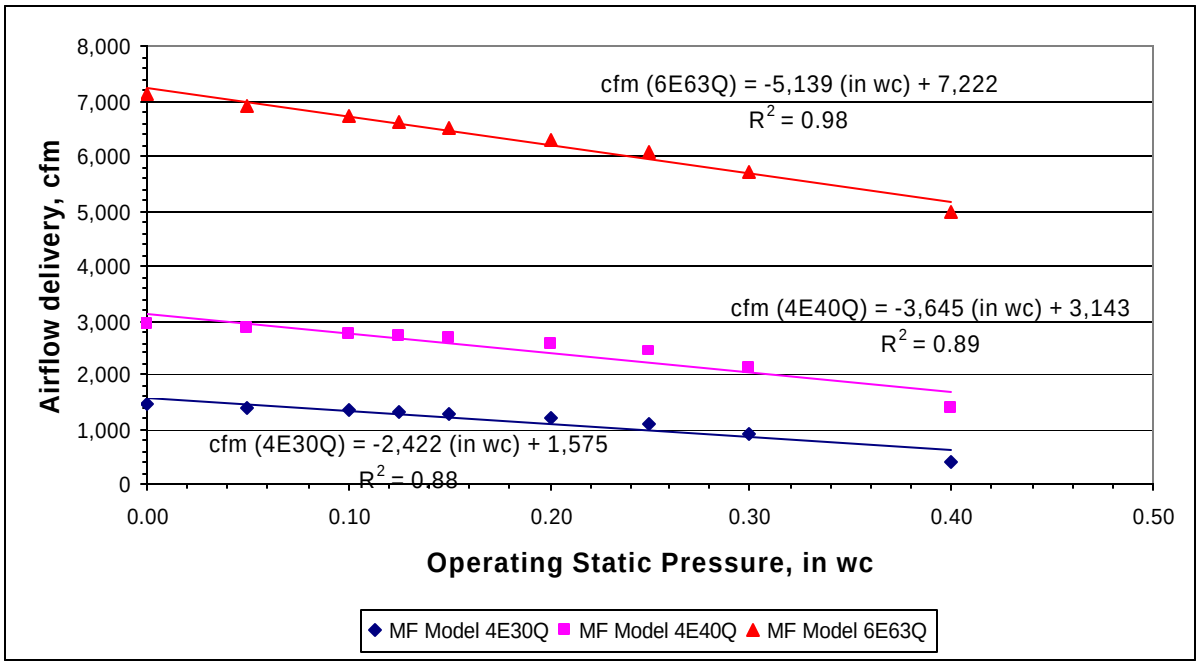
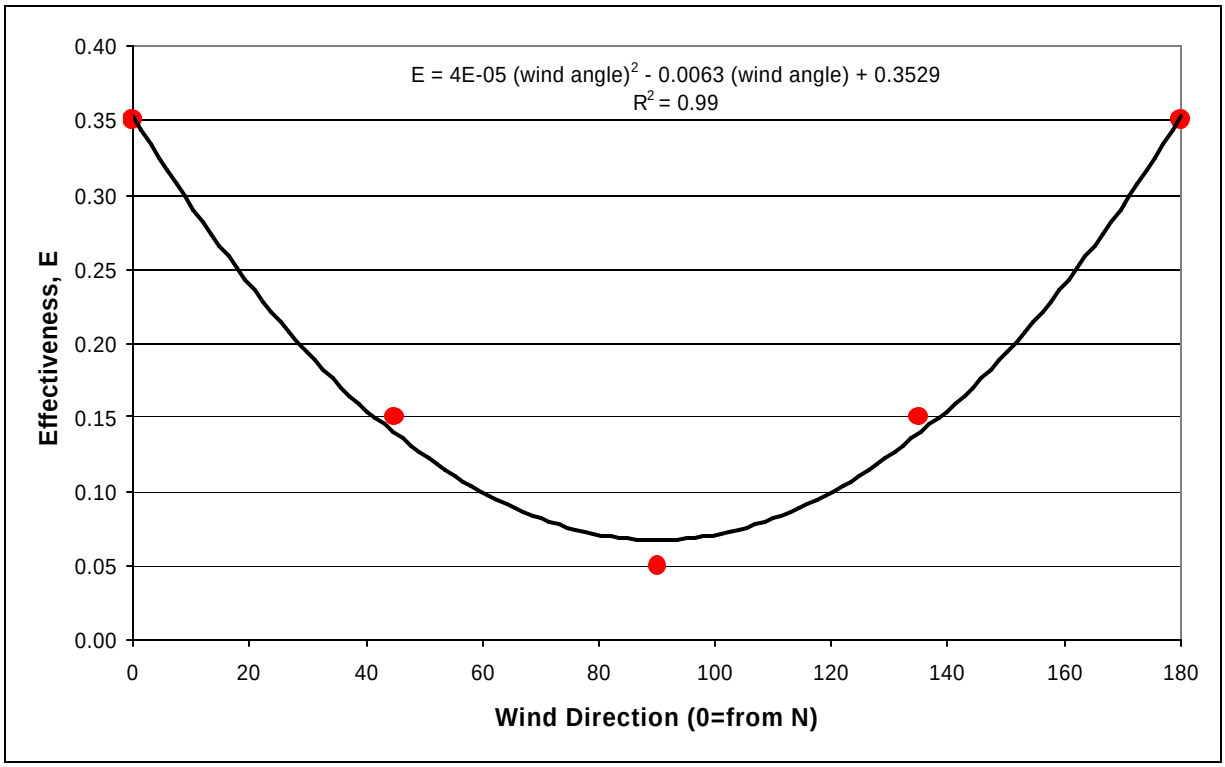
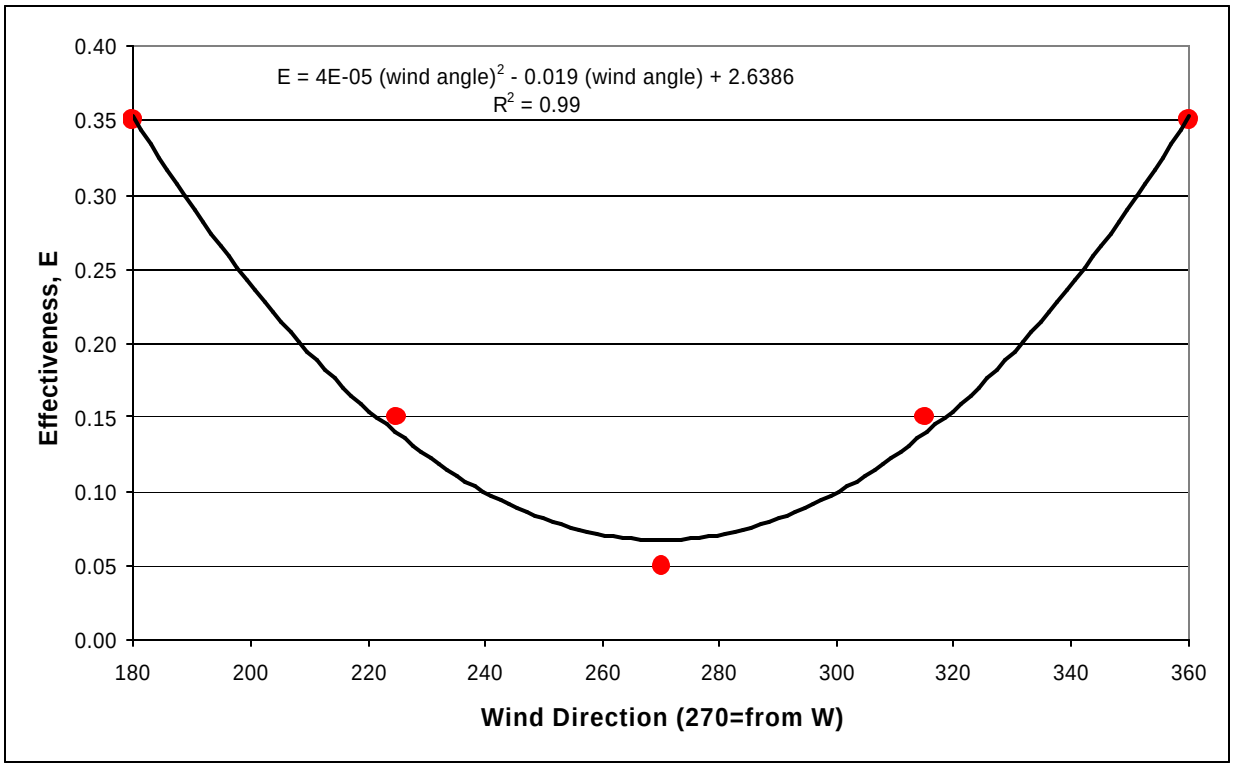



**Figure 19.** Fan curves used for the four biofilter fans installed. For airflow estimation purposes, 85% of the predicted values from these fan curves were used at any given operating static pressure.




**A**




**B**

**Figure 20.** Wind-driven ventilation effectiveness values (E) used for (A) 0-180 degree winds and (B) 180-360 degree winds.

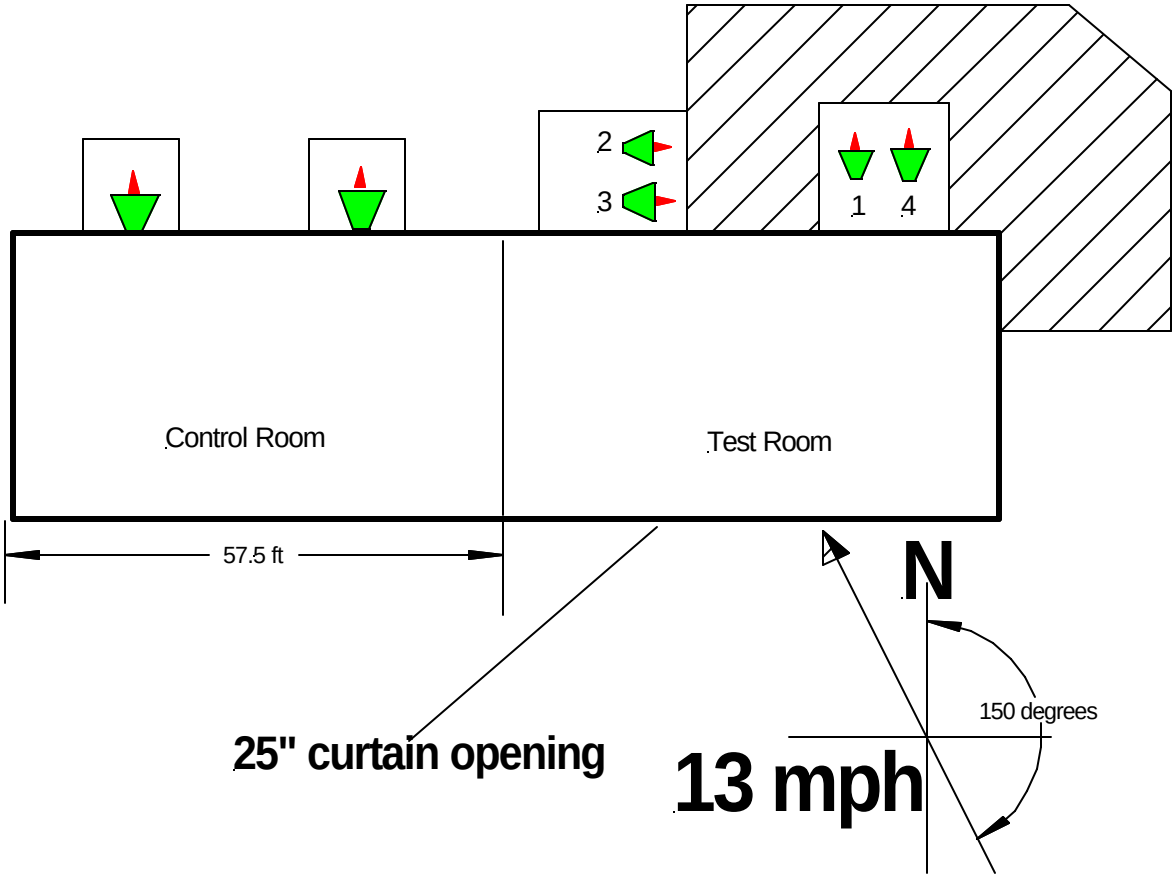
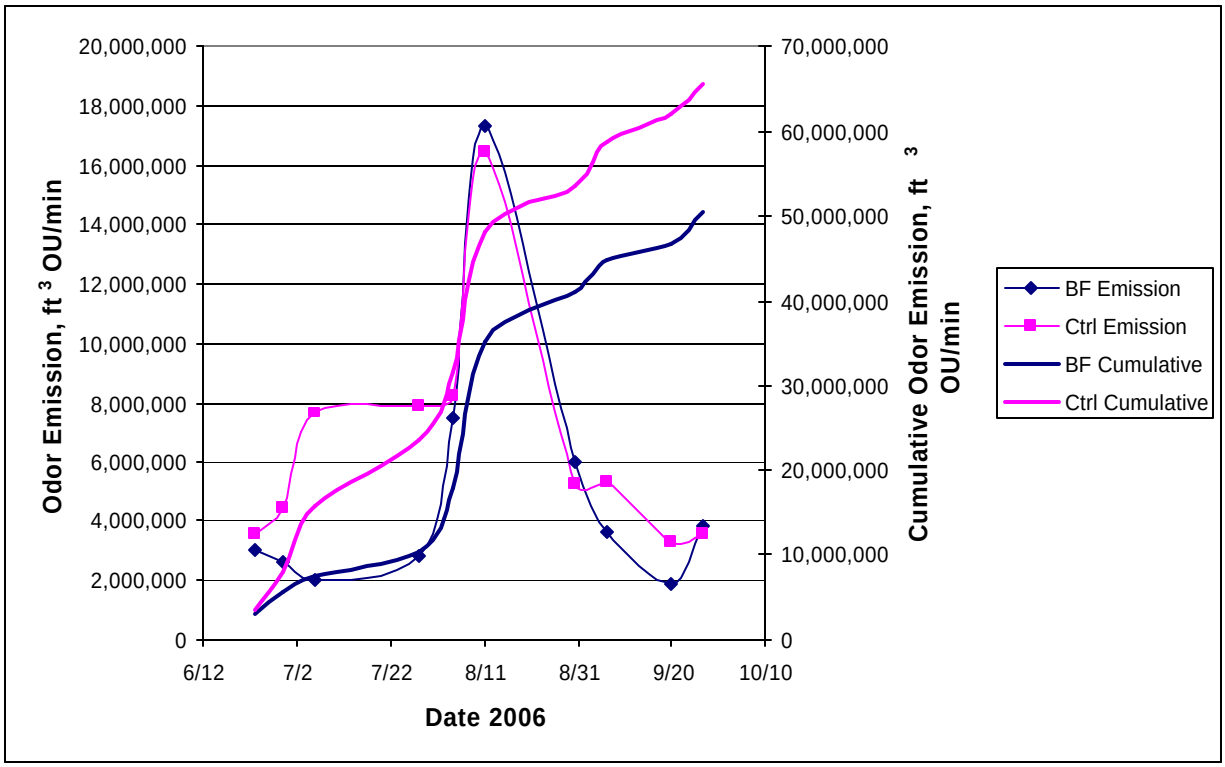
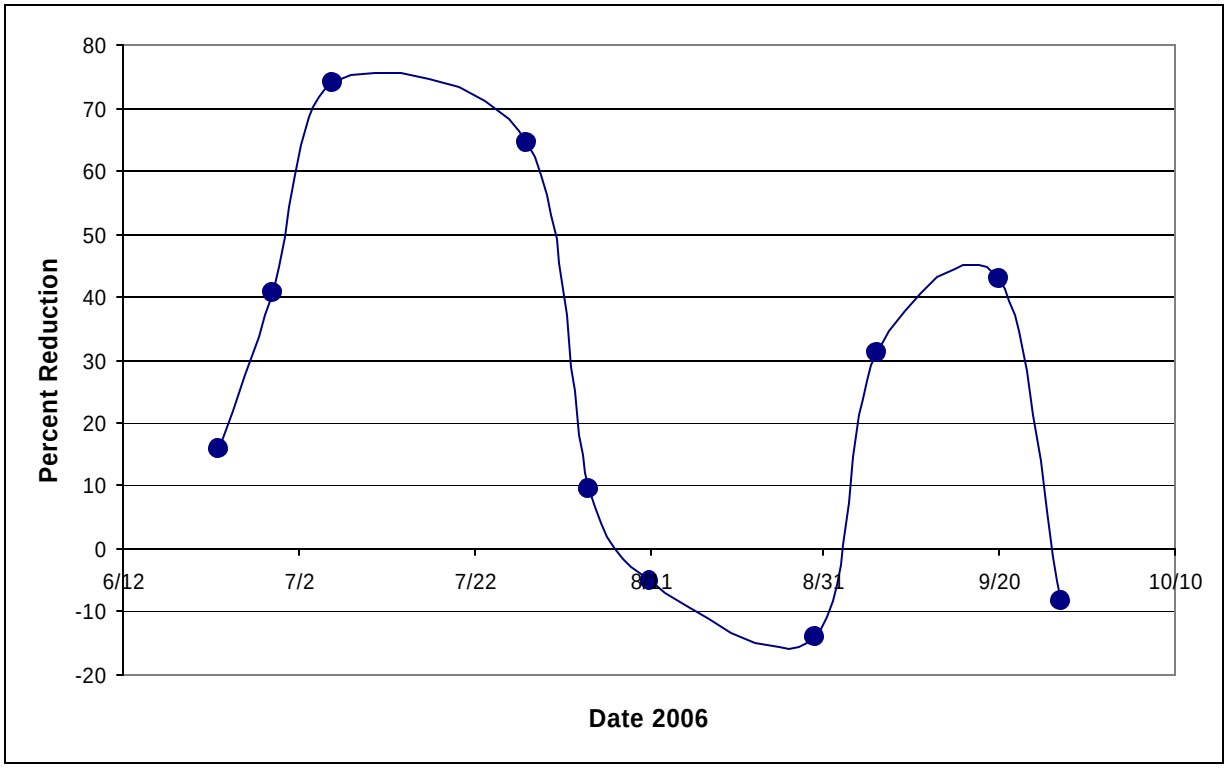



**Figure 21.** Wind-driven ventilation details associated with example calculations.




**A**




**B**

**Figure 22.** Odor emission estimations during 2006 for the biofilter (BF) and control (Ctrl) barns monitored. Cumulative difference also shown.

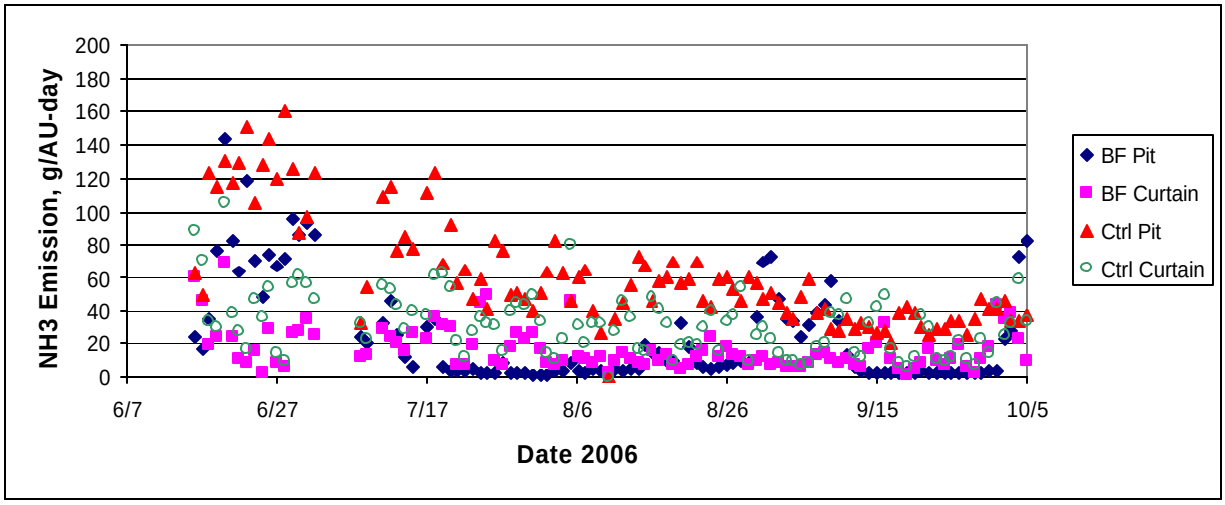
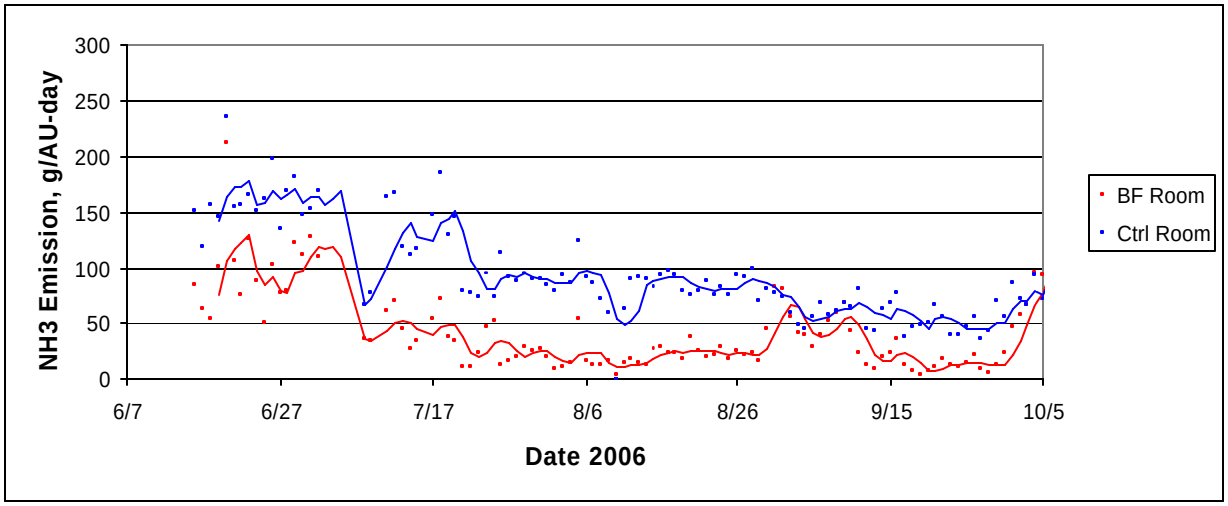
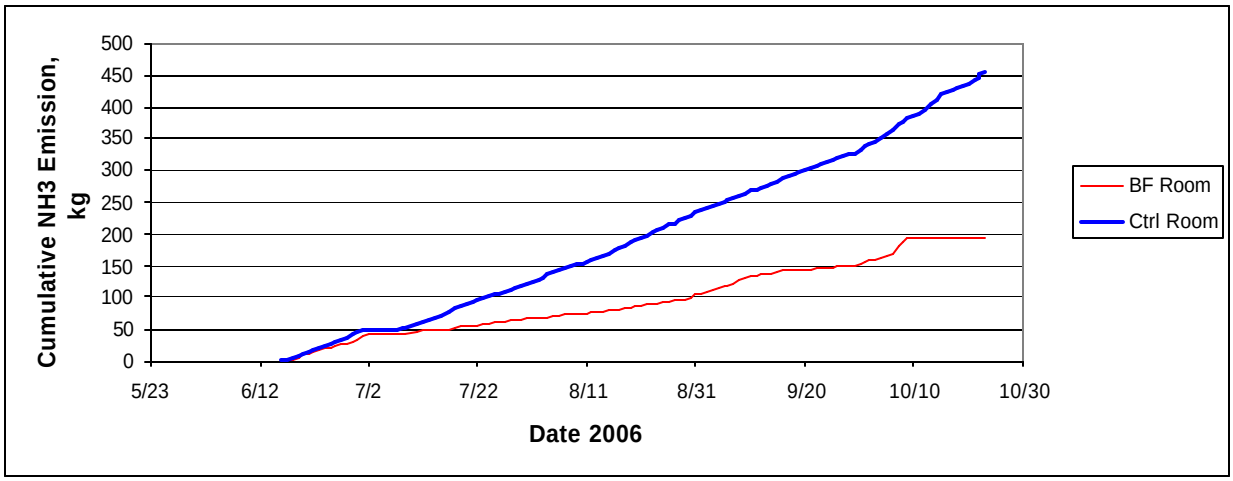



**Figure 23.** NH3 emission estimations during 2006 for the BF pit fans, BF curtains, Ctrl pit fans, and Ctrl curtains.




**A**




**B**

**Figure 24.** NH3 emission estimations during 2006 for the (A) BF and Ctrl rooms and (B) a comparison of the cumulative NH3 emissions throughout the 2006 monitoring period.

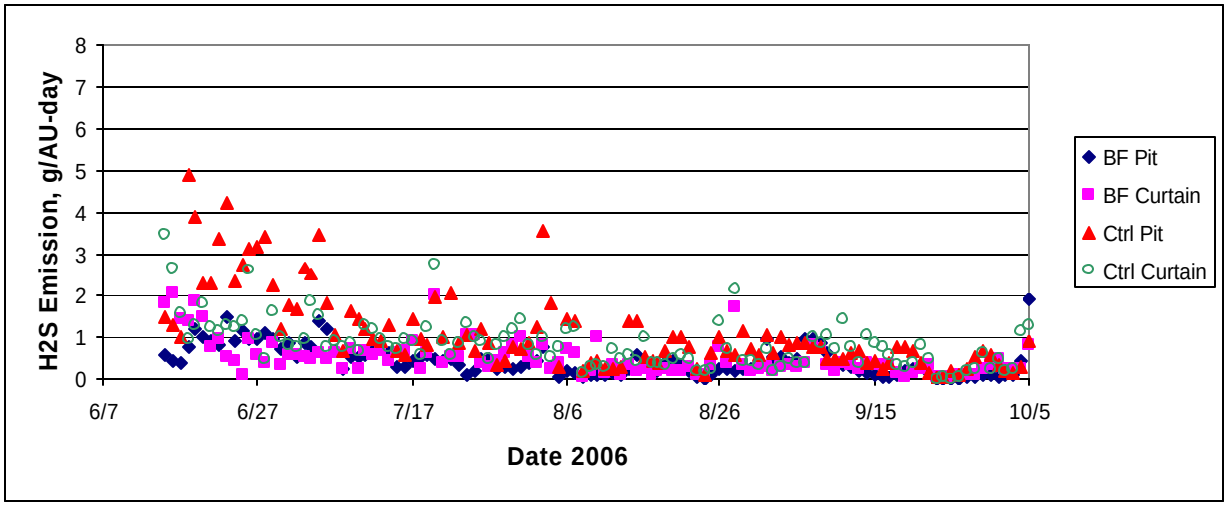
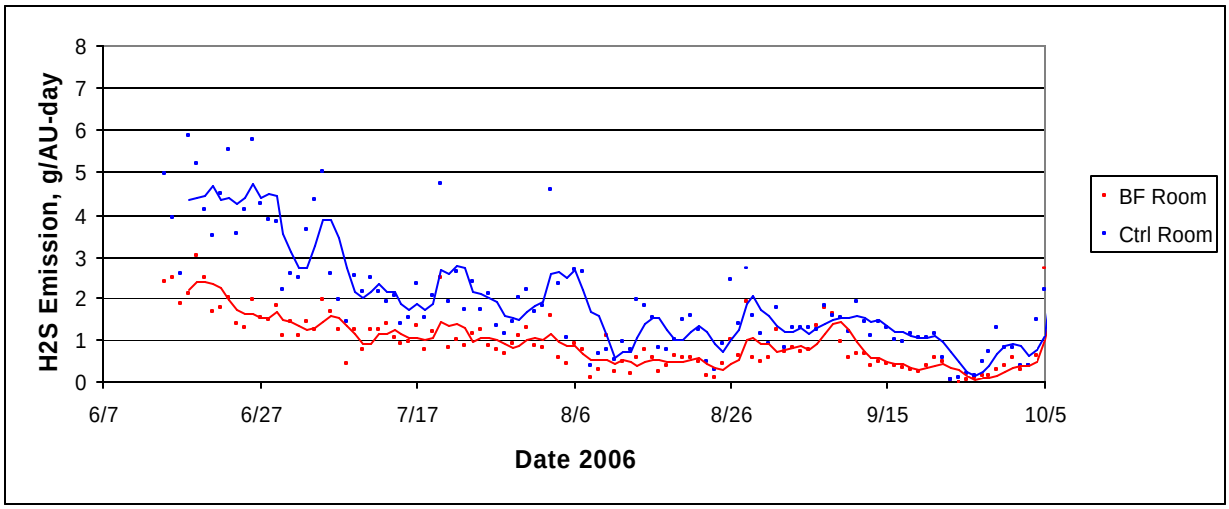
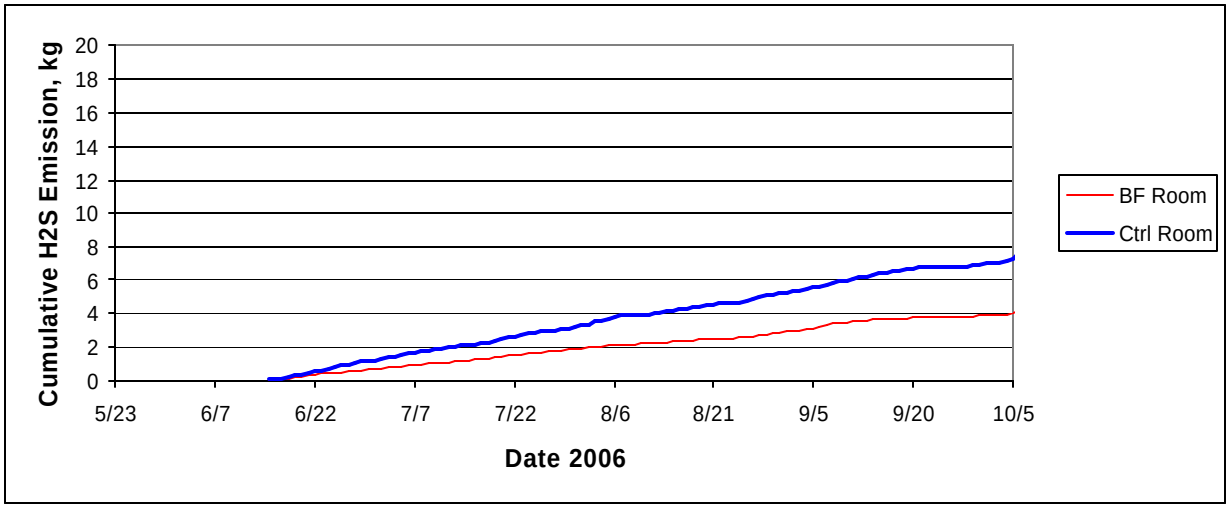



**Figure 25.** H2S emission estimations during 2006 for the BF pit fans, BF curtains, Ctrl pit fans, and Ctrl curtains.




**A**




**B**

**Figure 26.** H2S emission estimations during 2006 for the (A) BF and Ctrl rooms and (B) a comparison of the cumulative H2S emissions throughout the 2006 monitoring period.

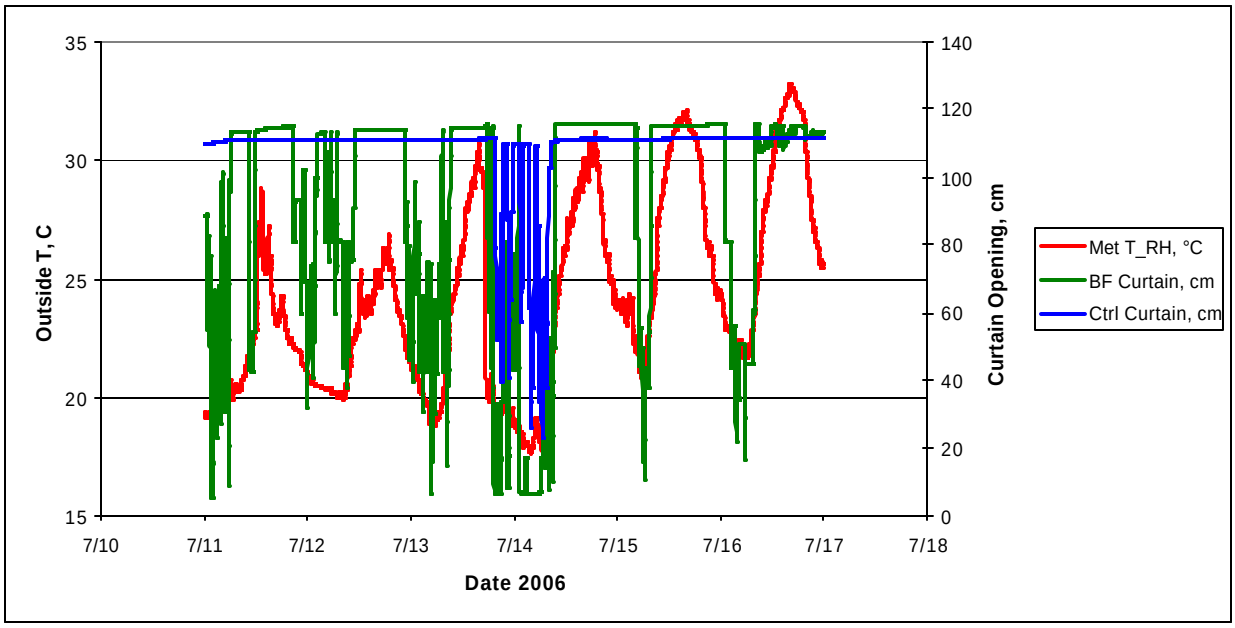



**Figure 27.** Comparison between BF barn and Ctrl barn curtain opening response in response to outside temperature.

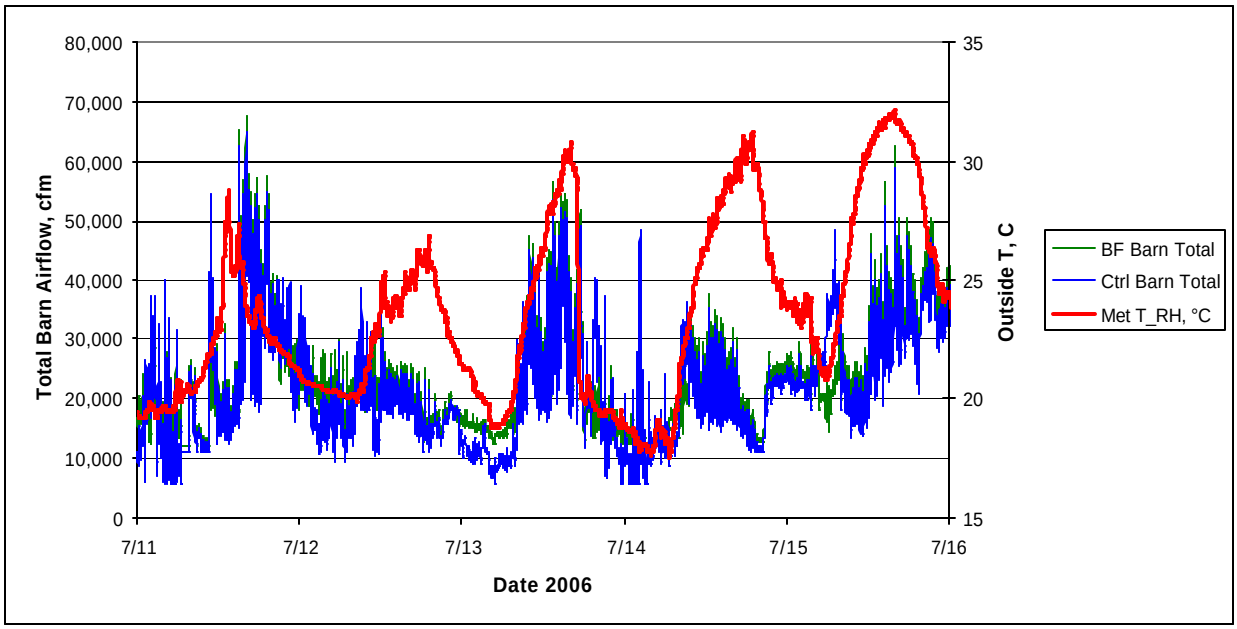



**Figure 28.** Comparison between BF barn and Ctrl barn total ventilation rates (fans+curtains).

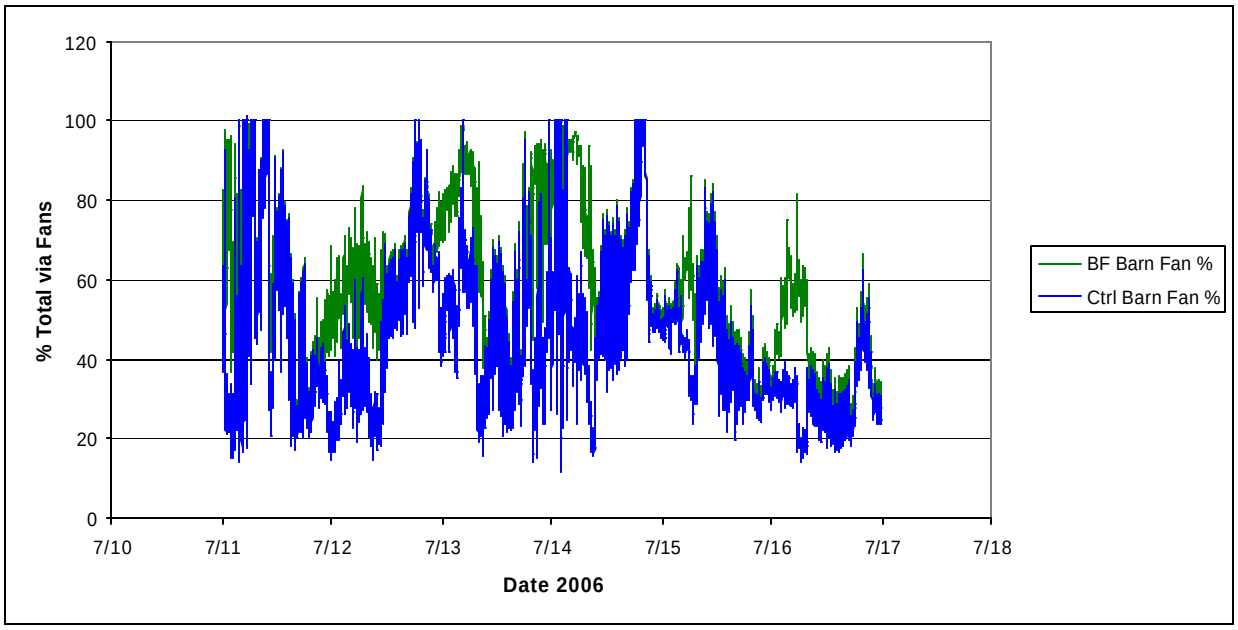



**Figure 29.** Percentage of total barn ventilation rate through the pit fan system.

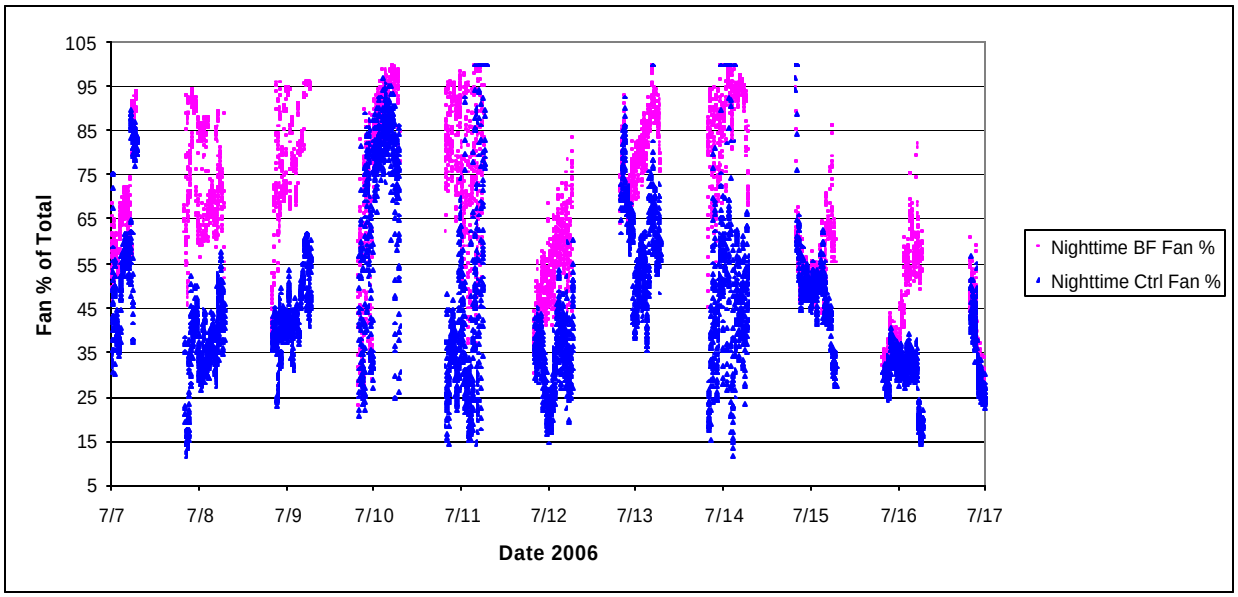



**Figure 30.** Comparison between nighttime fan percentage of total for the BF and Ctrl barns.

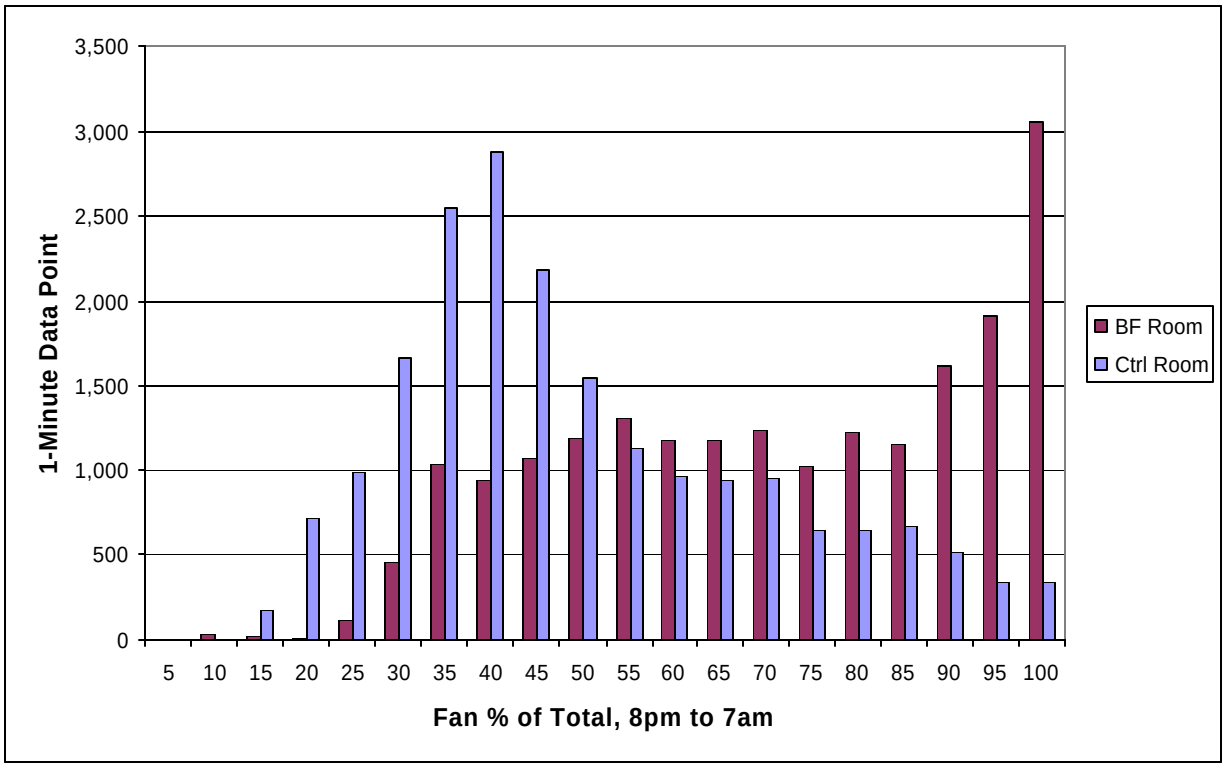



**Figure 31.** Histogram showing distribution of the fan percentage of the total for the BF and Ctrl rooms.

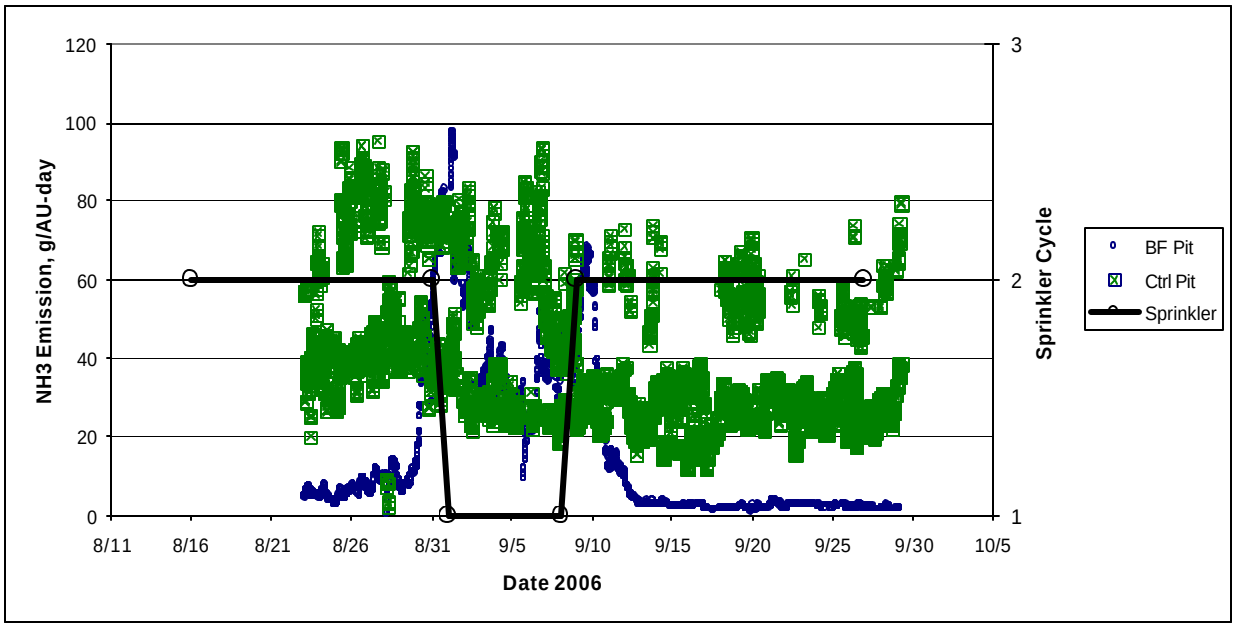



**Figure 32.** Ctrl and BF barn NH3 emission rates from the pit fans. The sprinkler trace signifies a period of time (sprinkler=1) where the water application rate was halved.