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Evaluation of Electrostatic Particle Ionization and BioCurtain Technologies to Reduce Dust, Odor and other Pollutants from Broiler Houses

Final Report

Prepared for:
Texas State Soil and Water Conservation Board

By:
Dr. Sheryll Jerez, Stephen F. Austin State University
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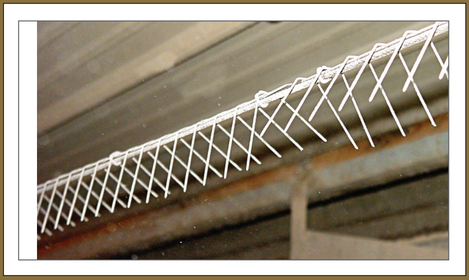
Texas A&M University System
College Station, Texas 77843-2118

Texas Water Resources Institute
make every drop count



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Executive Summary

Confined poultry production has increased in Texas and along with it, complaints of odor and dust. These issues are a major problem in the United States not only for confined animal health but also for the increasing urban migration to the rural areas where the poultry industry is expanding. Particulate matter and volatile organic compound (VOC) produced in the poultry houses can be offensive to neighbors, and if not properly vented, pose a serious health hazard to the animals. Some technologies available attempt to strike a balance between reducing poultry house emissions and maintaining bird health; however there is a lack of sufficient pollutant-reduction data to make a sound fiscal judgment in the implementation of this equipment. Two possible management tools that have shown promise and were chosen for evaluation during this project were an Electrostatic Particle Ionization (EPI™) system and a BioCurtain™.

The EPI™ system includes an antenna-like array of wire strung through the poultry house with a small electric charge running through it. The resulting electric field ionizes the particulate matter suspended in the air, causing it to attract to grounded materials.

The BioCurtain™ consists of a black geotextile fabric stretched over a quadrant-shaped, metal frame skeleton, and placed over the exhaust fans of the poultry houses. Air moving out of the house flows down along the top of the quadrant and particulate matter settles out on the ground. The air, without the particulate matter, then flows vertically out through the top of the BioCurtain™.

This project tested the effectiveness of a BioCurtain™ and Electrostatic Particle Ionization (EPI™) system in reducing NH_3, H_2S, and TSP emissions from a broiler house during short periods in September and December 2010. This project found:

1) A reduction of about 9%, in the emission of NH_3 and H_2S gases (1060 vs. 960 g/hr for NH_3 and 9.3 vs. 8.5 g/hr. for H_2S) in December when only the BioCurtain™ was active.
2) The BioCurtain™ resulted in a 34% (325 vs. 213 g/hr. in September) to 43% (396 vs. 227 g/hr in December) reduction in the TSP emission.
3) The EPI™ system reduced the NH_3 and TSP emission rates by as much as 17% and 39%, respectively.

Table of Contents

List of Acronyms and Abbreviations

ASABE—American Society of Agricultural and Biological Engineers
BAEN—Biological & Agricultural Engineering
BMP—Best Management Practice
DC—Direct Current
DQO— Data Quality Objectives
EPA—Environmental Protection Agency
EPI—Electrostatic Particle Ionization
FANS—Fan Assessment Numeration System
GSS—Gas Sampling System
H_2S—Hydrogen Sulfide
kV—kilovolts
NH_3—Ammonia
mA—milliamperes
PM—Particulate Matter
QA/QC—Quality Assurance/Quality Control
QAPP—Quality Assurance Project Plan
QPR—Quarterly Progress Report
SFA—Stephen F. Austin State University
SOP—Standard Operating Procedure
TAMU—Texas A&M University
TSP—Total Suspended Particulate Matter
TSSWCB—Texas State Soil and Water Conservation Board
TEOM—Tapered Element Oscillation Microbalance
TWRI—Texas Water Resources Institute
VOC—Volatile Organic Compound

Introduction

Problem/Need Statement

Dust and odor emissions from tunnel-ventilated poultry houses are a significant environmental issue for the US poultry industry, especially when poultry operations are located close to residential, commercial, or recreational areas. Odor, particulate matter (PM), and gas (ammonia, hydrogen sulfide, volatile organic compounds, etc.) emissions can have potentially harmful effects on the environment and the health of both humans and birds. The recent expansion of the poultry industry in Texas along with the increasing trend of people moving out into rural areas has led to the increased number of odor-related complaints. Poultry producers are under increasing pressure to reduce those impacts and need cost-effective solutions. New methods or technologies for abating environmental pollutants are in demand in order to mitigate these complaints. Numerous technologies are available on the market, but are expensive and lack sound pollutant reduction data that would allow producers to make an informed decision about purchasing such equipment.

A patented Electrostatic Particle Ionization (EPI™) system and a BioCurtain™ have shown promise for reducing ammonia and PM emissions from poultry facilities; however, there is little scientifically supported evidence to validate the claims associated with the EPI™ or BioCurtain™ systems. Moreover, information on the performance, costs, operational requirement, benefits and limitations of these technologies in different climatic condition are yet to be determined. The EPI™ technology utilizes an array of sharp-pointed stainless steel electrodes charged to -30kV (DC) to induce an electric field that negatively charges air ions, which are then attracted to grounded surfaces. The system is current-limited to no more than 2 mA to ensure worker and animal safety. The BioCurtain™ technology for reducing dust and odor consists of a metal frame structure covered with a woven geotextile fabric and functions by settling airborne dust particles on the ground after they are exhausted from the barn.

General Project Description

This project was the first of a two-phase project to design, install and verify the ability of the EPI™ and BioCurtain™ systems. The second phase will evaluate the ability of the installed and verified air pollution abatement BMPs to mitigate emissions from an individual house at a commercial scale broiler operation over a full 18-week growing cycle. The first phase of the project consisted of identifying a cooperating producer, conducting an on-site evaluation of the operation, and selecting the treatment and control houses. Two adjoining houses on the south end of the farm were selected for the project; the EPI system and BioCurtain were installed on one of these two houses. The management of both barns was identical and congruent with the cooperating producer's typical management strategies. The only potential difference was the total numbers of birds, which could change due to bird mortality throughout the flock's progression. Specific materials and methods are further described in the ASABE presentation paper in Appendix B.

Goals

The primary goal of this project was to install and verify the correct operation of the EPI™ and BioCurtain™ systems for reducing odor, dust, and harmful gas emissions from commercial poultry houses.

Task 1: Project Administration

Objective: To effectively administer, coordinate and monitor all work performed under this project including technical and financial supervision and preparation of status reports.

In the role of project administrator, TWRI reported on the project's progress quarterly along with budget status and disseminated reports to all project members; coordinated quarterly project meetings and other project meetings were held as needed. TWRI also maintained the project website.

Task 2: Quality Assurance

Objective: To develop data quality objectives (DQOs) and quality assurance/control (QA/QC) activities to ensure data of known and acceptable quality are generated through this project..

TWRI, with assistance from project partners, developed, and amended as necessary, a detailed QAPP for activities in Tasks 3 and 4 consistent with EPA Requirements for Quality Assurance Project Plans (QA/R-5) and the TSSWCB Environmental Data Quality Management Plan. All monitoring procedures and methods prescribed in the QAPP were consistent with the guidelines detailed in method-specific, peer reviewed, or widely accepted documents or SOPs describing the specific methods used.

Task 3: Poultry Farm Selection and Equipment Installation

Objective: To identify and select a poultry farm cooperator and install demonstration and monitoring equipment for technology demonstrations.

Project partners with assistance from Sanderson Farms scouted and selected a suitable producer and site for this project in Mexia, Texas. BAEN purchased the Bio Curtain™ and EPI™ systems and installed them in the selected house along with monitoring equipment and instruments in the control and treatment houses. These items included: air samplers; temperature, humidity, and static pressures sensors; a Fan Assessment Numeration System; and associated data loggers. BAEN also tracked the costs associated with the procurement, delivery, installation and retrofitting (poultry house) of the EPI™ and BioCutain™ systems and compiled the information into a brief summary of the expected capital and operational costs of purchasing this dust- and odor-mitigation system (Appendix A).

Task 4: BMP and Monitoring Systems Verification

Objective: To assess the proper functioning of the EPI™ and BioCurtain™ technologies and the monitoring equipment installed to evaluate their effects on mitigating environmental pollutants produced by confined commercial broiler operations.

BAEN and SFA tested the Biocurtain™ and EPI systems independently to ensure the proper operation of each system during two independent one-day trials for each system; one in the summer and one in the winter. BAEN and SFA operated and evaluated the EPI™ and BioCurtain™ system concurrently to ensure the proper operation of this dual-technology system. They tested this technology over two three-day period sessions, once during the summer and once during the winter. During all BMP tests, the project partners operated and maintained monitoring equipment in the control barn as well to ensure adequate comparison between treated and un-treated air during a long-term demonstration. A comprehensive description of the materials, methods and results are included in a paper presentation made to the ASABE (Appendix B).

Conclusion

This project tested the effectiveness of a BioCurtain™ and Electrostatic Particle Ionization (EPI™) system in reducing NH_3, H_2S and TSP emissions from a broiler building during short periods in September and December 2010. The findings of this project, as outlined in the ASABE presentation paper (Appendix B), include observations in:

1) A reduction in the emission rate of NH_3 and H_2S of about 9% (1060 vs. 960 g/hr. and 9.3 vs. 8.5 g/hr., respectively) in December when only the BioCurtain™ was active.
2) The BioCurtain™ resulted in a 34% (325 vs. 213 g/hr. in September) to 43% (396 vs. 227 g/hr. in December) reduction in the TSP emission.
3) The EPI™ system reduced the NH_3 and TSP emission rates by as much as 17% and 39%, respectively.

Investigators recommend that a second phase of this project should be completed over a full 18-week growing cycle, to evaluate the effectiveness of the combined systems and their TSP removal effectiveness over the extended period. Additionally, operation and maintenance cost data recorded for an entire flock will also be helpful to interested producers. These operation and maintenance costs, compiled with initial installation costs presented in Phase 1's interim report, will provide a more accurate picture of overall anticipated cost to purchase, install and operate this emission mitigation system, thus allowing producers to make informed decisions about the costs of the system versus its benefits.

Appendix A

Economic Analysis

EVALUATION OF DUST AND ODOR MITIGATION TECHNOLOGIES AT A POULTRY FACILITY

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Edited by
Aaron Hoff, Texas Water Resources Institute

An interim report submitted to
The Natural Resources Conservation Service
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Background

As concern for particulate matter (PM) emissions continues to grow as a result of expanded regulation, greater emphasis has been placed on identifying feasible solutions for reducing PM emissions from key sources (Cambra-Lopez et al. 2009). Poultry houses are one such source, where PM concentrations inside the facility can be 10 to 100 times higher than those normally found in residential buildings (Lee and Zhang, 2006). Though conventional means of air cleaning can be effective, the use of air ionization is beginning to see expanded use due to lower energy consumption and propensity to produce less hazardous by-products (Daniels 2001). Previous research shows that electrostatic particle ionization (EPI) systems are less effective in ventilated facilities (Grabarczyk 2001), so in buildings such as poultry houses, a second mitigation technique may need to be implemented in order to impound any remaining PM that has passed through the poultry house's exhaust fans. This can be achieved through the use of permeable geotextile enclosures placed over the exhaust fan array and placing a miniature EPI unit inside the enclosure to ionize any remaining PM in the air before it exits. This project tests the effectiveness of both technologies under different scenarios using a multi-phase approach on a pair of poultry houses in East Texas where residential growth is beginning to encroach on areas populated with poultry operations and air quality complaints are becoming common.

Economic Analysis

Fixed and variable costs of operating the automated electrostatic particle ionization system (The EPI system is automated for self-adjustment of corona lines for optimal ion flow through the system as seen in Figure 1) and the BioCurtain™ system (two systems, one per battery of mechanical ventilation fans as seen in Figure 2. Each BioCurtain™ includes a mini EPI system inside the BioCurtain™) for one 46' wide and 500' long broiler barn, housing an average of 23,000 birds, are provided in table 1. It is estimated that each barn houses five flocks of broiler chicken per year at a grow out rate of 63 days per flock. Useful working life of EPI and BioCurtain™ systems and repair and maintenance costs are assumed to be 10 years and 2% of the fixed cost, respectively. Two hours per week of labor cost for inspection of both systems per barn is also included in the cost estimates.

Figure 1. Corona lines running from power source.

Figure 2. BioCurtain installations on poultry house

For the EPI system, there are four power supply units that use a maximum of 103 watts of power per unit. Therefore, total power usage for the system is estimated to be 412 watts for 23 hours a day. The system is shutoff for cooling of power supply units for one hour during every 24 hours of operation. It is assumed that the EPI system runs for 315 days (5 flocks x 63 days/flock) per year. At $0.08 per kWh, the total cost of electricity is $ 239 per year per barn. For the two BioCurtain™ Systems per barn, the mini EPI system runs on one power supply unit at 103 watts. Assuming the same operation time for the mini EPI power supply unit as the main EPI system inside the barn, at $0.08 per kWh, the total cost of electricity is $60 per year per barn.

Table 1. Breakdown of the cost items used to estimate dust and odor mitigation cost.

Cost Items		Materials ($)	Labor ($)	Total Cost ($)
Fixed cost (for 10 years)	Two BioCurtain™ Systems	18,997	3,000	21,997
	EPI System	23,025	1,800	24,825
				Total Fixed cost = 46,822
Fixed cost per year per barn spread over 10 years				4,682 yr^{-1}
Variable cost (based on 315 days per year of operation)	Electricity Two BioCurtain™ Systems	0.103 kW × 23 h/d × 315 d × $0.08/kWh		60 yr^{-1}
	EPI System	0.103 kW × 4 units × 23 h/d ×315 d × $0.08/kWh		239 yr^{-1}
	Labor	1 labor × 2 h/wk × 45 wks × $10/h		900 yr^{-1}
	Repair and maintenance	2% of total fixed cost ($46,822) per year		936 yr^{-1}
				Variable cost = 2135 yr^{-1}

The estimated number of broiler birds finished per barn per year (23,000 birds × 5 flocks) is 115, 000. Therefore, the total cost (combined fixed and variable cost; $4,682 + $2135) of mitigation using the two technologies was estimated to be ($6817/115,000 birds) $0.059 per bird or about 6 cents per bird.

Maintenance of the Bio Curtain^{TM} and EPI Systems

The Vendor estimates that producers should set aside two hours per week for routine inspection and maintenance of the two systems by one person per broiler house.

Routine inspection and maintenance of Bio Curtain^{TM} include weekly inspection of curtain wear and tear and removal of excessive dust from the inside of the curtain surfaces using a power vacuum. Caution: To prevent electrical shock during cleaning of curtains The EPI System inside the curtains must be turned off so no electrical power is energizing the corona lines inside the curtain.

The Vendor has provided the following information on maintenance of various parts of the EPI system.

Regular Observational Maintenance and Recommendations

When walking through the barns on normal daily tasks, it is wise to observe the corona lines. Some basic observational maintenance can help keep the EPI System running smoothly.

- Look for broken ceiling insulators. The ceiling insulators keep the corona line from short-circuiting and do the lifting and lowering of the corona line. If they are broken, the chances of problems arising increase. Most ceiling insulators hold the corona line up, but some hold the corona line to the side or down, away from grounded objects. Replace broken insulators as soon as possible.
- Keep the corona points pointing toward the floor. Pressure washing between flocks occasionally causes the corona points to become tangled and point in odd directions. The EPI system works best when the corona points are pointing toward the floor as seen in Figure 3.

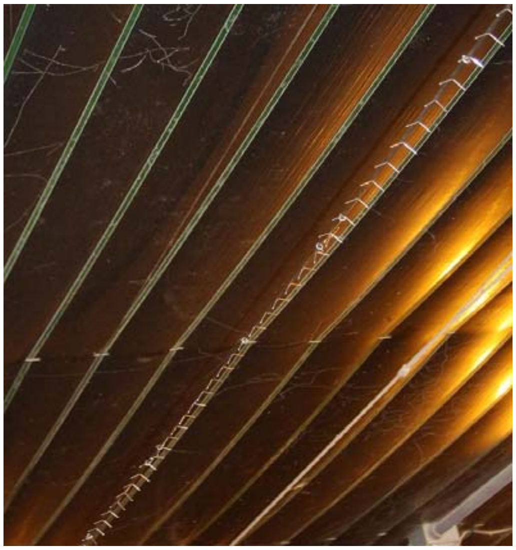

Figure 3. Corona lines for EPI system near roof of poultry house.

- Ground wires are connected to the ratchets, feeder lines, and water lines. All of these ground connections are important to the operation of the EPI system. The ground wire attached to the ratchets must be connected to the power supplies. The feeder lines and water lines are grounded via a connection from the center lifting cranks to the upper ground line of the EPI system. These grounds are important for keeping the feeder lines and water lines free of static charges.
- Never wash the power supplies with a pressure washer. The dust accumulation on the power supply needs to be kept clean, but do not use a pressure washer. There is a risk of damaging the power supplies. Use compressed air or a cloth to remove accumulated dust. (Dust accumulation on the power supply may cause it to become too hot, which can cause damage.)
- When washing the barns between flocks always unplug the power supplies to avoid the potential for electric shock.
- When walking past the power Supplies make sure the yellow light is on. If the yellow light is not on and the red light is on then, typically, a short-circuiting has occurred. The corresponding corona line should be walked to discover the short-circuiting.
- If no short-circuiting is evident; disconnect the HV wire from the power supply (unplug the power supply, loosen the black pressure fitting, and pull the HV wire out). Plug the power supply back in and if all three (green, yellow and red) lights turn on and stay on, then the power supply is functioning properly. Re-check the corona line for short-circuiting.
- If there are no lights on when looking at the power supply, make sure it is receiving power from the outlet. If the outlet has power, and the power supply is plugged in, but no light comes on, then the power supply is broken. If only the green light turns on, the power supply is broken. If only the green light and red light turn on (and no short-circuit is evident) the power supply is broken.
- If all three of the lights are on, and the voltage and amperage readings are “normal” the maintenance adjustment screw should be adjusted to a new setting.

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Appendix B

Paper presentation to ASABE

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Evaluation of Electrostatic Particle Ionization and BioCurtain™ Technologies to Reduce Air Pollutants from Broiler Houses

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***Abstract.**. The continuing growth of poultry production, along with the increasing urbanization of rural areas, is leading to more odor-related complaints from neighboring communities and more scrutiny from policy makers. It is therefore in the best interest of poultry producers to look at control methods for abating odors. Previous studies have shown that substantial amounts of volatile and odorous compounds are adsorbed and transported by dust particles. Thus, by reducing the amount of dust emitted from the poultry facilities such as broiler houses, odor may be reduced as well. The objective of this study was to evaluate the effectiveness of two commercially available control technologies (BioCurtain™ and electrostatic particle ionization (EPI™) system) in reducing the total suspended particulate matter (TSP), ammonia (*NH_3*), and hydrogen sulfide (*H_2S*) emitted from a broiler facility in Texas. The study was conducted at a broiler production facility in two identically designed, ventilated, and managed broiler houses where one served as the treatment house and the other, the control. Measurements were done on two consecutive days each in September and December 2010. BioCurtain™ was tested independently on the first day and in combination with and the EPI™ on the second day. Reductions in the* NH_3 *and* H_2S *emission rates by as much as 9% (1060 vs. 960 g/hr for* NH_3 *and 9.3 vs. 8.5 g/hr for* H_2S*) and by as much as 43% (396 vs. 227 g/hr) for the TSP emission rates were achieved with the BioCurtain™. The EPI™ system reduced the* NH_3 *and TSP emission rates by as much as 17% and 39%, respectively.*

Keywords. Ammonia Emission, BioCurtain™, electrostatic charging, ionization, odor emission, particulate matter, poultry housing

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Introduction

Although the number of animal farms in the United States has declined since reaching its peak in 1935 at about 6.5 million, the annual production of poultry has risen steadily over the past decades due to the increased farm size and the number of birds raised per farm (NAS, 2003). In terms of broiler production, the 25.6 billion pounds produced in 1990 almost doubled at 49.1 billion pounds in 2010, while the total value grew from $ 8.4 billion to $23.7 billion during the same time period (USDA-NASS, 2011). Broiler production in Texas ranks 6th in the nation, producing 3.6 billion pounds and generating $1.8 billion in revenue in 2010; the broiler produced in 2010 represented an increase of about 150% from 1990. In terms of growth relative to the 1990 levels, Texas was second only to Mississippi (approximate growth of 182%) (USDA-NASS, 2011).

The continuing growth in poultry production in Texas, and intensive animal production systems in general, led to increased number of odor-related complaints from communities in close proximity to these facilities. In an effort to address the increasing odor complaints, the Texas Commission on Environmental Quality (TCEQ) requires to investigate odor complaints concerning a poultry facility, or the land application of litter by a poultry facility, within 18 hours if the complaint is the second against the same facility pursuant to Senate Bill 1693. Given the increasing attention from policy makers and the public, it is in the interest of the poultry producers to look at control methods for abating odors as well as other environmental pollutants from their facilities.

The dissemination of odorous compounds occurs through two principal mechanisms: present in vapor phase and carried by dust particles. Substantial amounts of volatile and odorous compounds such as ammonia and hydrogen sulfide emitted from animal buildings are adsorbed and transported by dust particles (Hammond et al., 1981; Donham et al., 1986; Parbst, 1998; Lee and Zhang, 2006). Thus, by reducing the amount of dust emitted from the building, some of which may be carried as far as several miles, odor may be reduced as well. Hangartner (1990), for example, reported that filtering dust from the exhaust air reduced the VOC-odor emissions from swine buildings by up to 65% - evidence that dust VOC-odor is associated with airborne dust particles.

A variety of strategies and control technologies are available for controlling odor and other air pollutants from confined animal structures. There are those technologies that can capture and treat air pollutants such as biofilters, biotrickling filters, and air scrubbers (Kennes and Veiga, 2002; Melse and Mol, 2004; Melse and Ogink, 2005; Chen et al., 2009; Park et al., 2011). These technologies rely on the use of filter media where pollutants will be entrained and attached and their use for removing gaseous pollutants (i.e. ammonia, hydrogen sulfide, odorous compounds) found some successes. However, these technologies are not yet commercially available in the United States.

Two approaches for reducing emissions of particulate matter (PM) are a BioCurtain™ and an electrostatic precipitator. A BioCurtain™ relies on filtration mechanisms of impaction and interception to separate PM from the exhaust air stream. An electrostatic precipitator charges the particles to move them out of the gas stream and onto the collector plates (Zhang, 2005). Studies have also shown that another function of an electrostatic precipitator system can be to kill airborne and surface microorganisms as demonstrated by Mitchell et al. (2004). They used an electrostatic space charge system (ESCS) in a broiler breeder house to effectively reduce airborne dust, ammonia, and airborne bacteria by an average of 61%, 56%, and 67%, respectively. In a related study, the ESCS was also effective in reducing the airborne dust and gram-negative bacteria, in experimental room containing broiler breeder pullets, by an average of 37% and 64%, respectively (Richardson et al., 2003). The Electrostatic Particle Ionization (EPI™) systems used in a pilot broiler house reduced PM_{10} and $PM_{2.5}$ by 36% and 10%, respectively (Cambra-Lopez et al., 2009).

The objective of this study was to test the effectiveness of a patented Electrostatic Particle Ionization (EPI™) system combined with a BioCurtain™ in reducing PM and gases (ammonia and hydrogen sulfide) in a broiler facility. Although the use of an EPI™ has been reported before (e.g. Cambra-Lopez et al., 2009), there is very limited evaluation data that would help the producers make informed decisions about purchasing the system. In addition, there has been no reported research data on the effectiveness of a combined EPI™ system and BioCurtain™ in reducing PM and gases from the exhaust air streams of poultry buildings in the United States.

Methodology

Experimental Design and Description of the Broiler Houses

The study was conducted in two identically designed, ventilated, and managed broiler houses located in Mexia, TX. The Electrostatic Particle Ionization (EPI™) system and BioCurtain™ were installed in one of the houses, which served as the treatment house; the other adjoining house served as the control. Measurements were done on two consecutive days in September 2010 to represent the warm weather condition, and another two consecutive days in December 2010 represented the cold weather conditions in TX. On day one of each sampling period, the EPI™ system was turned off so that the effectiveness of the BioCurtain™ alone can be tested; on the second day, the performance of the combined EPI™ and BioCurtain™ was evaluated.

The farm chosen for this study had 11 broiler buildings with a 15-m distance in between the buildings. With the prevailing southerly wind direction, the two adjoining buildings located on the south end of the farm were selected so that the exhaust fans on the south side of the treatment building can be properly analyzed. Both broiler houses were bedded with new litter consisting of wood shavings. This eliminated the effect of the bedding material age on emissions of gases. Each of the buildings was 152.4 m long, 14 m wide, with a peak ceiling height of 3.7 m, and the long axis oriented east-west. They were tunnel-ventilated with nine, 137 cm and two, 122 cm axial exhaust fans (six on the south sidewall and five on the north sidewall (Figure 1) near the east side of the buildings. Additionally, two minimum ventilation, 91 cm, fans were installed on the east end wall of each building. Two sidewall tunnel air inlets; one on the south sidewall and one on the north sidewall (1.5 m high and 26 m long with a 15 cm thick cooling pad) were located on the east end of each building. There were drop-down ceiling inlets installed against both sidewalls to provide fresh air into the building. All fans had discharge diffuser cones. Each building had alternating water (four) and feed (three) lines that ran along the length of the building starting and ending at about 3 m from each end of the building.

The buildings were populated with approximately 24,300 birds per flock during warm weather of June through September and 25,700 birds per flock during all other months immediately after hatching and grown until the market age of 63 days with an approximate weight of 3.6 kg. Sampling was done when the birds were 59-60 days old in September and 60-61 days old in December. The birds were fed through the auto feeders and nipple drinking system that ran the entire length of the house.

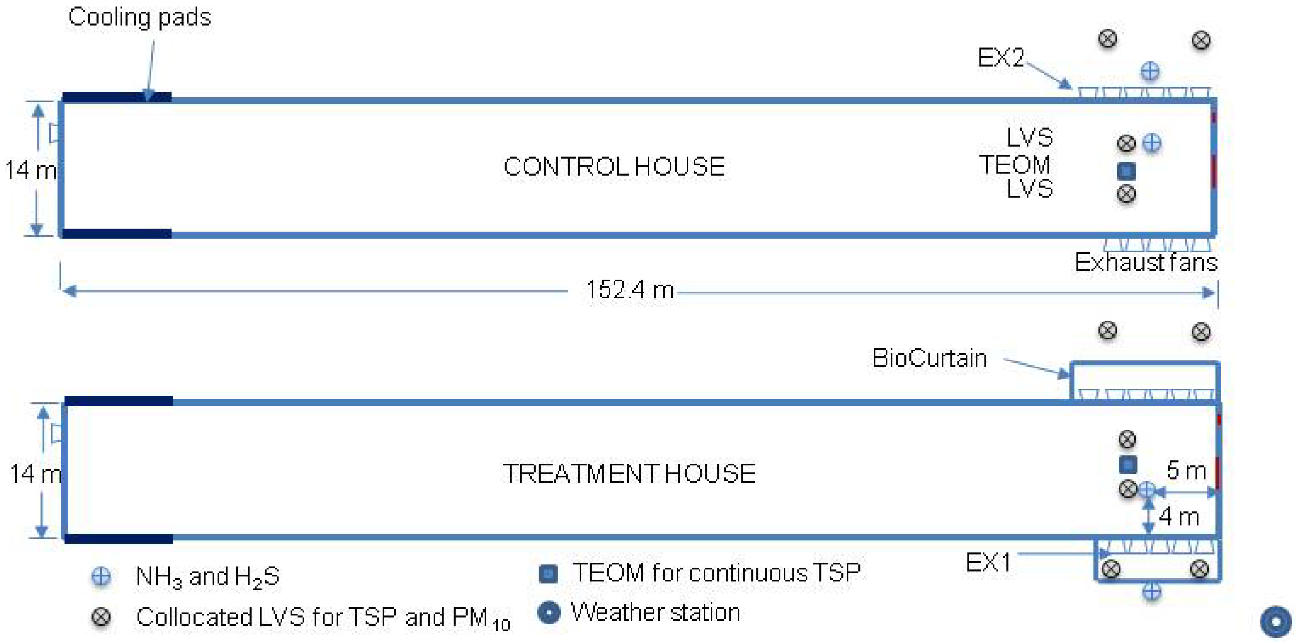


Figure 1. Schematic of the plan view of the broiler houses showing the sampling locations for TSP, PM_{10}, NH_3, and H_2S (not drawn to scale).

Description of the Electrostatic Particle Ionization (EPI™) System

The EPI™ system (Baugmgartner Environics Inc., Olivia, MN) installed inside the treatment house consisted of four rows of inline, negative ionization units (consisting of conductive wires with discharge electrodes) that are suspended 30 cm from the ceiling and ran along the entire length of the house (Figure 2). Each of these ionization units was attached to a high voltage power supply to generate -30kV DC (at a low current level of up to 2 mA) to ensure safety. The high-voltage negative corona discharge occurs at the stainless-steel electrodes located at 2.54 cm intervals and is pointed toward the litter as shown in Figure 3. The negative corona imparts negative charge to the airborne particles as they flow through the charging field causing them to be attracted to grounded surfaces such as floor, walls, ceilings, and other surfaces in the building.

Figure 2. The ionization units hanging from the ceiling of the broiler treatment house and connected to the power supplies.

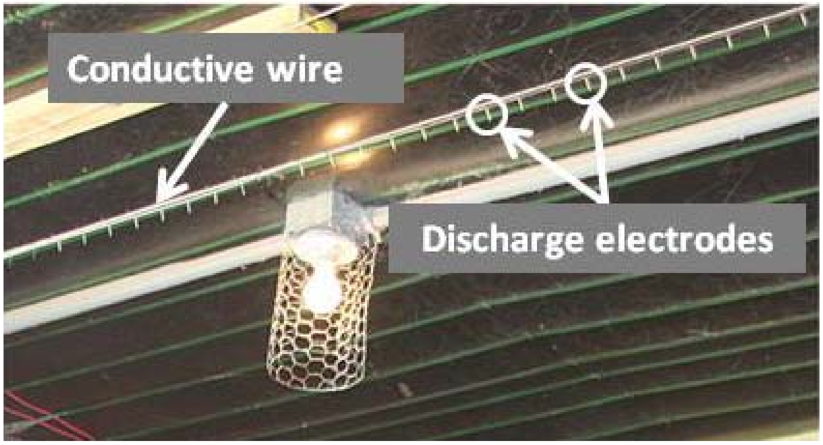


Figure 3. Detail of the discharge electrodes attached to the conductive wire of the EPI™ system.

Description of the BioCurtain™ With an EPI™ System

The BioCurtain™ system (Baugmgartner Environics Inc., Olivia, MN) is comprised of a metal frame structure, covered with a woven geotextile fabric used to enclose a group of ventilation fans. It was installed about four fan diameters away from the exhaust fans covering the entire exhaust area on both sides of the building (Figure 4). Each curtain was 12.2 m long and 5.5 m wide.

Figure 4. Biocurtain covering the entire exhaust area on both sides of the treatment house. Treated air leaves vertically and through the opening near the bottom corner of the structure.

The BioCurtain™ functions by altering the aerodynamics of the air being exhausted from the barns by directing it toward the geotextile fabric and down into the bottom corner of the structure, where dust settles out of the air stream. The treated air is then exhausted out vertically and through the opening near the bottom corner of the structure (Figure 4). An EPI™ system was also installed inside the BioCurtain™ (Figure 5) enclosure to enhance the collection of suspended particles before the treated air leaves the structure.

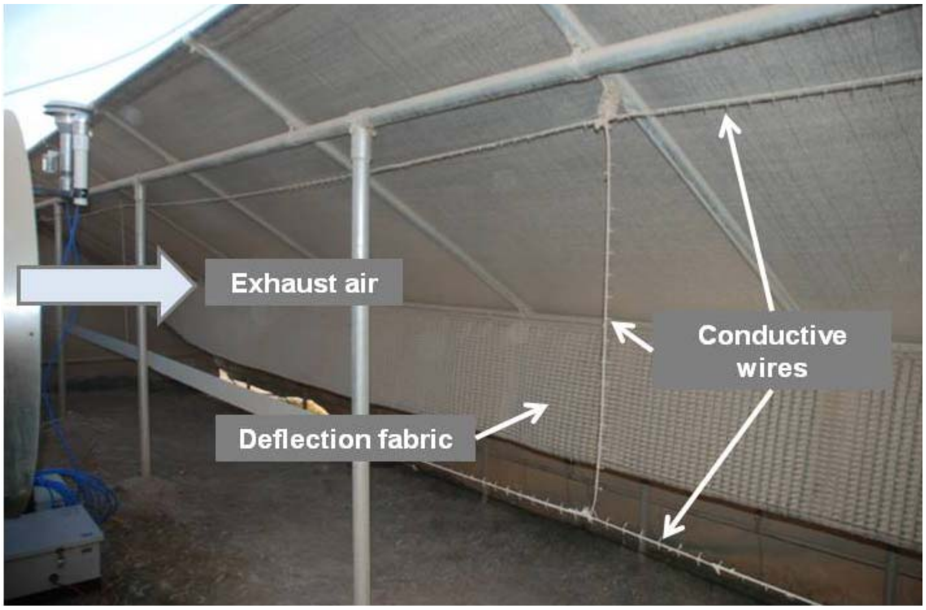


Figure 5. An EPI™ system installed in the BioCurtain™ enclosure to enhance the removal of PM.

Measurement of TSP Concentrations

Concentrations of the total suspended particulate matter (TSP) in both the treatment and control houses were measured using gravimetric samplers. A Tapered Element Oscillating Microbalance (TEOM) monitor (Series 1400a, Rupprecht and Patashnick Co., Inc., Albany, NY) fitted with a TSP inlet was used for the continuous measurement of the mass concentration inside the two houses. The TEOM monitor was collocated with two low-volume TSP and PM_{10} samplers (LVS) (Wanjura et al., 2005) with 47-mm Teflon filters. The filters were conditioned in a desiccator for 24 hours prior to and after sampling. All measurements inside the treatment and control buildings were taken at the center of the fan hubs of EX1 and EX2 in Figure 1 and at three fan diameters (4 m) upstream of EX1 and EX2. Outside the barns, LVS samplers fitted with TSP and PM_{10} inlets were used for the measurements inside of the biocurtain enclosing EX1 in the treatment house and at about 7 m away from EX2 of the control house (Figure 1).

Measurement of Ammonia and Hydrogen Sulfide Concentration

Ammonia (NH_3) and hydrogen sulfide (H_2S) concentrations were measured continuously using a chemiluminescence NH_3 analyzer (Model 17i, Thermal Environmental Instruments (TEI), Franklin, MA) for NH_3 concentrations and a pulsed fluorescence SO_2 detector (TEI Model 45C, Thermal Environmental Instruments (TEI), Franklin, MA) connected to a converter (TEI Model 340, Thermal Environmental Instruments (TEI), Franklin, MA) for the H_2S concentrations. Both analyzers were calibrated in the laboratory using standard gases prior to measurements. They were connected to the gas sampling system (GSS) shown in Figure 6 that allowed the analyzers to be housed in a mobile trailer parked at the site. The GSS consisted of a set of 3-way isolation valves that were controlled by a datalogger (Model 850, Campbell Scientific, Logan, UT), a pump (Model no. 420-1901, Thermo Scientific, Franklin, MA), and a separate datalogger (Model CR3000, Campbell Scientific, Logan, UT) for the analyzers. The sampling lines connected to the intake port of the isolation valves were 19.1 mm diameter Perfluoroalkoxy (PFA) tubing and insulated to minimize condensation inside the tubing. A 47-mm PFA filter holder containing a polytetrafluoroethylene (PTFE) membrane filters (5 µm pore size, Savillex Corp., Minnetonka, MN) was located at the intake side of all four sampling lines to filter out dust in the sampled air.

Similar to the TSP measurements, NH_3 and H_2S concentrations were measured at 4 m upstream of EX1 and EX2 and at the center of the fan hubs. To determine the concentrations at the exhaust, measurements were taken immediately outside and at the center of the BioCurtain™ opening in the treatment barn (Figure 1) and immediately downstream of EX2 in the control buildings (Figure 1). Concentrations were monitored sequentially, switching from one location to the next every 15 min. Concentrations were measured every 15 sec and the averages were recorded using the CR3000 datalogger every minute.

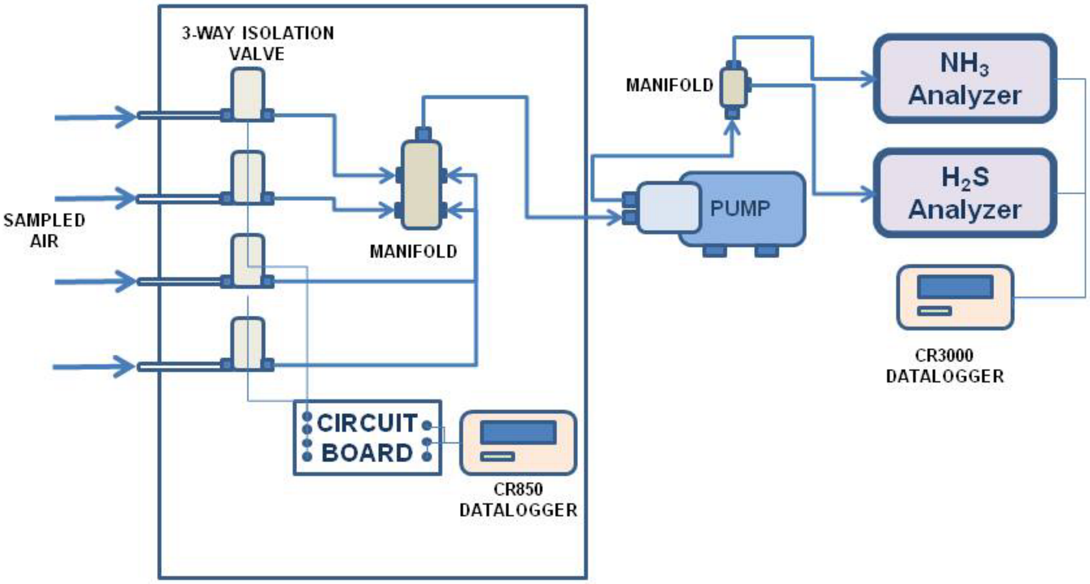


Figure 6. Schematic of the gas sampling system for NH_3 and H_2S.

Measurements of Ventilation Rates and Environmental Parameters

The performance curves of fans in both buildings were determined prior to sampling using a Fan Assessment Numeration System (FANS), which is a portable fan system consisting of multiple traversing impellers. The FANS generated air volumetric flow rates that corresponded to a range of static pressure. During sampling, the ventilation rate in each building was measured by manually recording the exhaust fans that are in operation and measuring the static pressure drop in the building using pressure gages. The performance curves generated with the FANS were used to determine the corresponding flow rates.

The temperature and relative humidity in the buildings were measured using Hobo dataloggers (HOBO® RH Temp, Onset Computer Corporation, Pocasset, MA) that were positioned at five locations in the building spaced about 30 m apart starting from the center of the exhaust fan hub. A portable weather station was installed SE of the treatment house. (Figure 1). Temperature, relative humidity, wind speed and direction were obtained from this site. For the calculation of emission rates of gases, atmospheric pressure data were obtained from a weather station at Corsicana Airport in TX (station no. 483491051).

Data Analysis

The amount of dust collected on the filters was the difference between the weights of the loaded filter and its clean weight before sampling. TSP concentration was the mass of dust collected divided by the total volume of the sampled air. The total volume of the sampled air was the product of the sampling flow rate and the sampling duration. Filters were conditioned for 24 hours prior to and after sampling and an analytical balance with a 10 µg resolution was used to determine the mass of dust collected.

The emission rates of TSP, NH_3, and H_2S were calculated by multiplying the concentrations of these parameters by the building ventilation rates. For example, the emission rates for NH_3 and H_2S were calculated using Equation 1. For NH_3 and H_2S data analysis, the pre-equilibrium concentrations (first 3 min of a 15-min sampling period) measured when the sampling location was switched were not used in the analysis.

$$E = Q \times \frac{C_{gv} \times M}{8.3145\left(\frac{T_e + 273.16}{P}\right)} \times 10^{-3} \qquad \text{Equation 1}$$

Where:

E = gas emission rate, mg/hr

Q = building ventilation rate, m^3/hr

C_{gv} = gas concentration at the exhaust sampling location, ppm

M = gas molecular weight, 17.03 g/mol for NH_3, 34.08 g/mol for H_2S

T_e = temperature at the exhaust sampling location, °C

P = atmospheric pressure, Pa

The proc glm procedure of the analysis of variance (ANOVA) was used to determine if there were statistically significant differences between the means of the environmental conditions, NH_3, H_2S, and TSP concentrations and emission rates in the control and treatment houses, and to determine the effect of the BioCurtain™ and EPI™ system on emissions abatement.

Results and Discussion

Environmental Conditions

Table 1 provides the environmental conditions (ventilation rate, temperature and relative humidity) in the control and treatment poultry houses. The temperature and relative humidity between the two house did not vary significantly (p>0.05). The temperature in September ranged from 23.2°C to 32.8°C and from 14.1°C to 21.7°C in December. The fluctuation in relative humidity in December (from 24.1% to 88.4%) was higher than that in September (from 55.8% to 99.1%). In September, the average temperature and relative humidity outdoors during the two days of sampling were almost similar while in December, the average temperature was lower and the relative humidity was higher on the second day than on the first day of sampling. The daily average ventilation rates between the control and treatment buildings did not differ by more than 28%.

Shown in Figure 7 are the wind roses in September and December. In September, the mean wind direction was almost South (170° from North) and the dominant wind velocity was from 0.5 to 2.1 m/s (frequency of 55%). During the two sampling days in December, the mean direction of the wind was SSE (146° from North) and the prevailing wind velocity was also from 0.5 to 2.1 m/s (frequency of 58.3%).

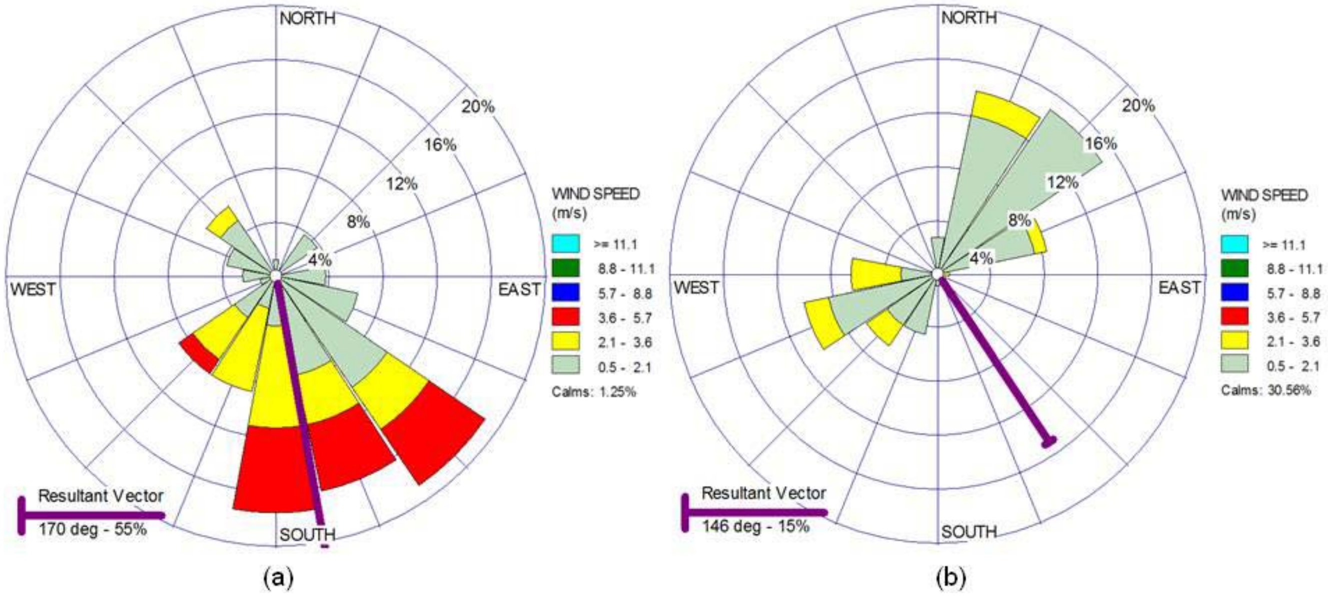
Table 1. Environmental conditions inside and outside the control and treatment poultry houses.

Sampling Day	Temperature,°C							
	Control House				Treatment House			
	Ave	SD	Min	Max	Ave	SD	Min	Max
23-Sep-10	27.3	1.0	23.2	29.5	27.3	1.1	23.6	32.8
24-Sep-10	27.0	1.2	23.2	28.7	26.8	1.2	23.2	28.7
7-Dec-10	17.7	1.0	14.1	21.3	17.6	1.2	14.5	21.7
8-Dec-10	17.5	0.8	14.1	20.6	17.0	1.2	14.1	20.6

Sampling Day	Relative Humidity, %							
	Control House				Treatment House			
	Ave	SD	Min	Max	Ave	SD	Min	Max
23-Sep-10	80.9	6.5	65.8	96.3	77.9	6.6	55.8	93.8
24-Sep-10	87.5	6.5	74.4	99.2	85.8	7.2	73.1	99.1
7-Dec-10	52.1	17.7	24.1	87.0	51.1	18.3	24.0	87.0
8-Dec-10	69.7	8.1	38.8	88.4	65.6	7.9	42.9	84.5

Sampling Day	Ventilation Rate, m^3/hr							
	Control House				Treatment House			
	Ave	SD	Min	Max	Ave	SD	Min	Max
23-Sep-10	317812	78119	126834	364589	326897	2478	317955	336914
24-Sep-10	332671	61519	126834	443168	305754	53179	163105	331961
7-Dec-10	91516	34120	47165	138571	117069	23990	79260	166033
8-Dec-10	98123	42351	22784	190509	85918	22176	48669	129523

Sampling Day	Outside Conditions							
	Temperature,°C				Relative Humidity, %			
	Ave	SD	Min	Max	Ave	SD	Min	Max
23-Sep-10	29.7	2.978872	23.0	33.3	59.8	16.25341	65.8	96.3
24-Sep-10	28.7	3.479027	21.9	32.5	68.2	17.13845	48.7	98.0
7-Dec-10	10.9	3.550362	1.3	14.3	33.2	10.50138	23.8	65.0
8-Dec-10	6.4	2.243369	2.5	9.8	74.9	14.79181	53.6	96.7



(a) (b)

Figure 7. Wind roses during (a) September and (b) December sampling periods. Resultant vectors indicate the mean direction the wind is blowing from and the magnitude of the resultant vector is represented by the frequency count. WRPLOT View version 6.5.1 of Lakes Environmental was used to generate the plots.

Effect of the BioCurtain™

The average concentrations of NH_3 in the treatment and control houses measured in September when only the BioCurtain™ was in operation are shown in Figure 8. The average NH_3 concentration upstream of the exhaust fans in the treatment house was only slightly higher by 4.3% (6.3 vs. 6.0 ppm). Downstream of the exhaust fans, the average NH_3 concentration in the treatment house was significantly lower by about 25% (6.4 vs. 8.0 ppm) ($p<0.05$). The H_2S concentrations were below the detection level of the analyzer. Despite the NH_3 concentration being significantly lower at the treatment house than in the control house, there was no reduction in the NH_3 concentrations going into and exiting the BioCurtain™ (6.3 vs. 6.4 ppm). In terms of the emission rate, the incoming and exiting NH_3 were not significantly different at the 5% level (1440 vs. 1455 g/hr).

In December, the NH_3 and H_2S concentrations between the treatment and control houses upstream of the exhaust fans were about the same (Table 3). Downstream of the exhaust fans, the concentrations of both NH_3 and H_2S were lower in the treatment house than in the control house by about 15 and 9%, respectively although these differences were not significantly different ($p>0.05$). There was no reduction in the NH_3 and H_2S concentrations going into and exiting the BioCurtain™ in the treatment house. However, in terms of the emission rate, the NH_3 and H_2S decreased by about 9% (1060 vs. 960 g/hr for NH_3 and 9.3 vs. 8.5 g/hr for H_2S).

Presented in Table 4 is the comparison of the concentrations of TSP between the treatment and control houses. The average concentrations of TSP in the treatment and control houses were about the same in both September (993 vs. 975 µg/m^3) and December (3640 vs. 3620 µg/m^3). Significant differences were detected between the TSP emission rates going into the BioCurtain™ and exiting the BioCurtain™ in both September and December sampling periods.

The BioCurtain™ resulted in a 34.4% reduction of TSP emission in September (325 vs. 213 g/hr) and 43% reduction in December (396 vs. 227 g/hr).

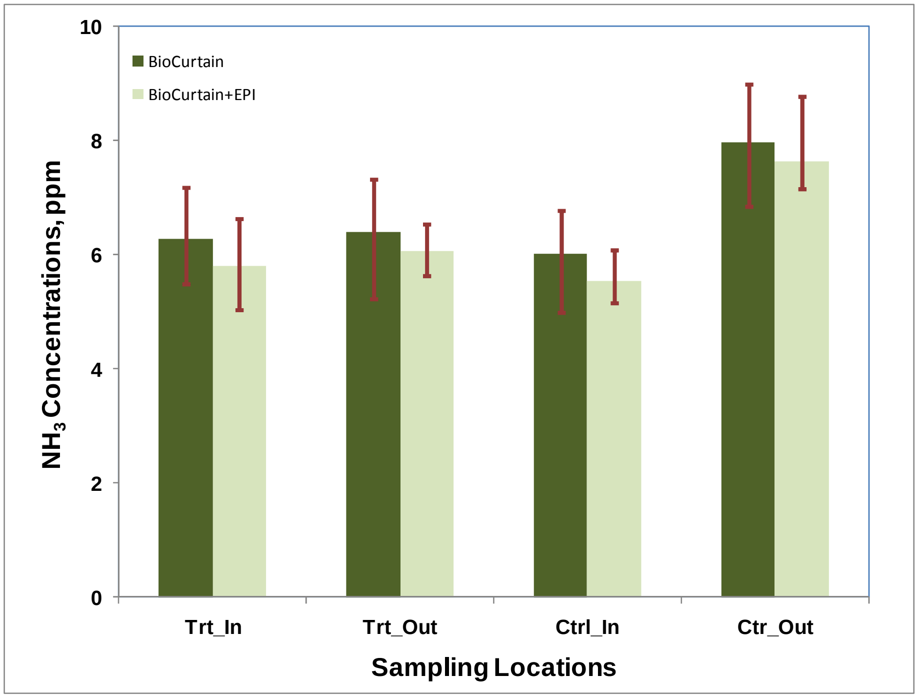


Figure 8. Comparison of the NH_3 concentrations measured in September 2010 when only the BioCurtain™ was in operation and when both the BioCurtain™ and EPI™ are active. The error bars represent the minimum and maximum values. Trt=treatment, Ctrl=control, In=upstream of the exhaust fans, Out=downstream of the exhaust fans.

Table 2. Comparison of NH_3 and H_2S concentrations and emission rates measured in September when only the BioCurtain™ was in operation and when both the BioCurtain™ and EPI™ are active.

Location[1]	BioCurtain			
	NH_3, ppm		NH_3, g/hr	
	Ave	SD	Ave	SD
Trt_In	12.2	2.5	1440.1	106.3
Trt_Out	10.6	3.9	1454.6	139.9
Ctrl_In	12.0	2.4	1286.7	434.6
Ctr_Out	12.2	2.3	1809.2	451.3

Location	BioCurtain and EPI							
	NH_3, ppm		H_2S, ppb		NH_3, g/hr		H_2S, g/hr	
	Ave	SD	Ave	SD	Ave	SD	Ave	SD
Trt_In	5.80	0.42	17.88	2.01	1201.1	248.5	7.3	1.6
Trt_Out	6.07	0.30	17.64	1.32	1259.6	253.8	7.3	1.5
Ctrl_In	5.55	0.33	17.74	1.20	1341.9	60.6	8.6	0.7
Ctr_Out	7.63	0.50	19.76	2.19	1719.9	202.4	8.6	0.9

[1] Trt=treatment, Ctrl=control, In=upstream of the exhaust fans, Out=downstream of the exhaust fans.

Table 3. Comparison of NH_3 and H_2S concentrations and emission rates measured in December when only the BioCurtain™ was in operation and when both the BioCurtain™ and EPI™ are active.

Location[1]	BioCurtain							
	NH_3, ppm		H_2S, ppb		NH_3, g/hr		H_2S, g/hr	
	Ave	SD	Ave	SD	Ave	SD	Ave	SD
Trt_In	5.8	0.4	17.9	2.0	1059.8	247.1	9.3	1.8
Trt_Out	6.1	0.3	17.6	1.3	960.4	340.7	8.5	2.9
Ctrl_In	5.5	0.3	17.7	1.2	851.0	357.8	7.6	3.8
Ctr_Out	7.6	0.5	19.8	2.2	850.3	282.3	7.2	2.3
Location	BioCurtain and EPI							
	NH_3, ppm		H_2S, ppb		NH_3, g/hr		H_2S, g/hr	
	Ave	SD	Ave	SD	Ave	SD	Ave	SD
Trt_In	16.51	3.47	49.16	30.77	1031.4	203.2	6.2	4.0
Trt_Out	17.47	2.42	45.23	31.28	1162.9	147.4	6.1	4.1
Ctrl_In	16.87	3.83	49.94	33.20	1093.0	557.3	6.9	5.2
Ctr_Out	17.26	3.89	55.41	30.56	978.6	417.9	6.5	4.3

[1] Trt=treatment, Ctrl=control, In=upstream of the exhaust fans, Out=downstream of the exhaust fans.

Table 4. Comparison of the concentrations and emission rates of TSP measured in September and December when only the BioCurtain™ was in operation and when both the BioCurtain™ and EPI™ are active.

Location[1]	September				December			
	BioCurtain		BioCurtain and EPI		BioCurtain		BioCurtain and EPI	
	Concentration $\mu g/m^3$	ER g/hr	Concentration $\mu g/m^3$	ER g/hr	Concentration $\mu g/m^3$	ER g/hr	Concentration $\mu g/m^3$	ER g/hr
Trt_In	993.00	325	607	199	3640	396	3610	266
Trt_Out	-	213	-	134	-	227	-	138
Ctrl_In	975.00	-	450	-	3620	-	4170	-
Ctr_Out	-	-	-	-	-	-	-	-

[1] Trt=treatment, Ctrl=control, In=upstream of the exhaust fans, Out=downstream of the exhaust fans.

Effect of the EPI™ System

The concentrations of NH_3 and H_2S when both the BioCurtain™ and the EPI™ system are in operation are presented in Table 2 and Figures 8 and 9. There were no significant differences between the concentrations of NH_3 and H_2S in the treatment and control houses in both September (5.8 vs. 5.6 ppm for NH_3; 17.9 vs. 17.8 ppb for H_2S) and December (16.5 vs. 16.9 ppm for NH_3; 49.2 vs. 50.0 ppb for H_2S). The NH_3 and H_2S concentrations downstream of the exhaust fans of the treatment house in September were significantly lower than that of the control house (6.1 vs. 7.6 ppm for NH_3 and 17.6 vs. 19.8 ppb for H_2S) while they were not significantly different in December ($p>0.05$).

The effect of the EPI™ on the concentrations and emission rates were determined by comparing the means between day 1 (when only the BioCurtain™ was in operation) and day 2 of sampling (when both the BioCurtain™ and EPI™ are in action). There was a significant reduction of 53% for the NH_3 concentrations from day 1 to day 2 in September (12.2 vs. 5.8 ppm) while the NH_3 and H_2S concentrations significantly increased in December. It should be noted that despite of the significant reduction in NH_3 in September, the average NH_3 concentrations were lower for both treatment and control houses on day 2 than on day 1 and the reduction may be attributed to other factors. Conversely, the NH_3 and H_2S concentrations in both houses were higher on day 2 than on day 1. In September, the EPI™ significantly reduced the emission rate of NH_3 by 16.6% (from 1440 to 1201 g/hr) ($p<0.05$). A non-significant reduction of about 3% was obtained in December for NH_3 emission rates (from 1060 to 1031 g/hr) while the EPI™ significantly reduced the H_2S emission rates (from 9.3 to 6.2 g/hr) by 34%.

Significant differences were detected in TSP concentrations in the treatment house between day 1 and day 2, when the EPI™ was activated. TSP concentrations were reduced by 39% in September (993 vs. 607 $\mu g/m^3$). Similar to the gases in September, the TSP concentrations in the treatment house were lower on day 2 than on day 1. In December, no significant differences were detected in the TSP concentrations in the treatment house between day 1 and day 2 indicating that the EPI™ system had no significant impact ($p>0.05$).

Lacey et al. (2003) reported that PM10 emissions from tunnel ventilated broiler facilities can be estimated using the equation:

$$PM_{10} = 2.44 \times 10^{-5} \times Wt$$

where PM_{10} is the emission rate per bird (gram/day/bird) and Wt is the average bird weight (g). In September, there were 25,051 birds harvested from Barn 1 with an average weight of 8.91 pounds (4042 grams). From Barn 2, 24,600 birds were gathered with an average weight of 8.61 pounds (3905 grams). Applying the equation from Lacey et al. (2003), PM_{10} emissions of 102.9 g/hr from Barn 1 and 97.7g/hr from Barn 2 were expected.

In September, PM_{10} emissions from the BioCurtain™ measured using FRM PM_{10} samplers Barn 1 on Day 1 averaged 73.6 g/hr, but emissions into the BioCurtain™ (calculated by multiplying the average ventilation rate by the average interior concentration) were only 39.1 g/hr. The same phenomenon was observed on day 2 with an emission rate into the BioCurtain™ of 25.4 g/hr and an emission rate out of the BioCurtain™ of 40.6 g/hr.

The increase in calculated emission rates may be explained by the wind-speeds encountered by the samplers at the outlet of the BioCurtain™. The PM_{10} samplers (which are only tested at wind-speeds up to 24 kmh) were exposed to high wind velocities at the outlet of the BioCurtain™ as the full ventilation airflow of a bank of fans was forced through a small opening in which the samplers were placed. The high wind speeds may lead to artificially high penetration of particles through the sampler inlet and onto the filter. Because the magnitude of these phenomena is currently unknown, the concentrations of PM_{10} measured at the outlet of the BioCurtain™ using FRM samplers should be analyzed cautiously.

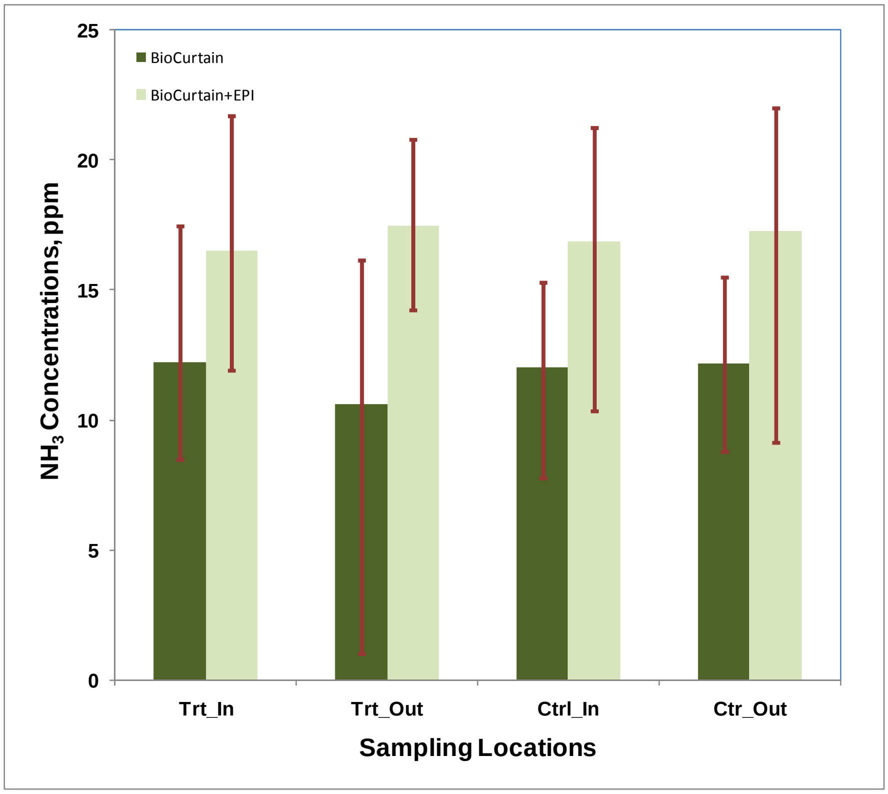


Figure 9. Comparison of the NH_3 concentrations measured in December 2010 when only the BioCurtain™ was in operation and when both the BioCurtain™ and EPI™ are active. The error bars represent the minimum and maximum values. Trt=treatment, Ctrl=control, In=upstream of the exhaust fans, Out=downstream of the exhaust fans.

Conclusion

This study tested the effectiveness of a BioCurtain™ and Electrostatic Particle Ionization (EPI™) system in reducing NH_3, H_2S, and TSP emissions from a broiler building. Measurements were done in September and December 2010. The following conclusions were drawn from this study:

- A reduction in the emission rate of NH_3 and H_2S of about 9% (1060 vs. 960 g/hr for NH_3 and 9.3 vs. 8.5 g/hr for H_2S) was achieved in December when only the BioCurtain™ was active.
- The BioCurtain™ resulted in a 34% (325 vs. 213 g/hr in September) to 43% (396 vs. 227 g/hr in December) reduction in the TSP emission.
- The EPI™ system reduced the NH_3 and TSP emission rates by as much as 17% and 39%, respectively.

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Appendix C

EPI Installation Manual

Materials List:

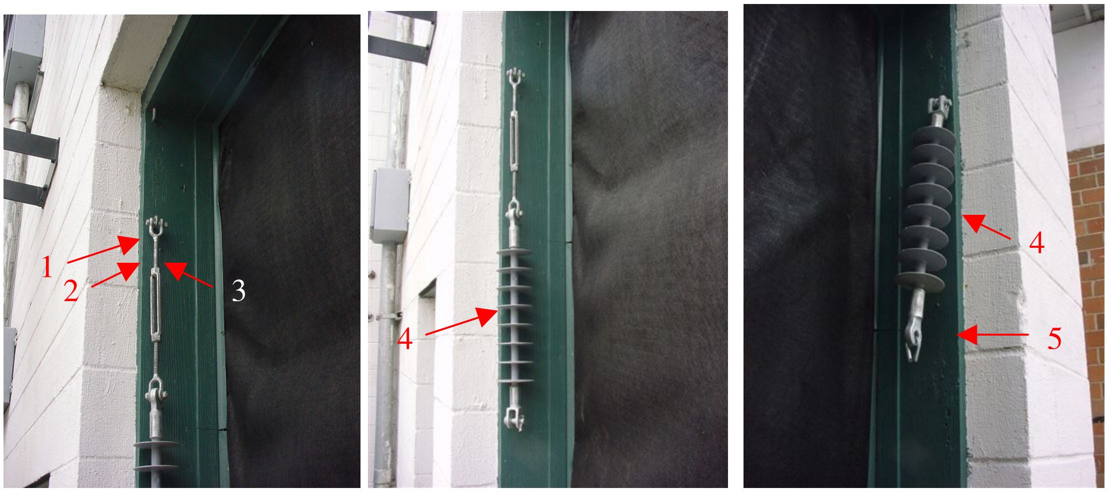
End insulators
Corona points
Cable
Power supply
Insulation tube
Grounding wire
Wire rope clips
Self-tapping screws
Cage rings
Anchors (eye lags)
Turnbuckles
Ceiling brackets
Zip ties
Optional ss anchors
Ceiling insulator
Power cords
High voltage tape
Timer
High voltage wire
Springs
Split bolt connector
Pulleys
Ratchets
Lag hooks
Lag screws

Tools List:

Drill/bits/concrete bits
Nut driver
Vice grip (locking pliers)
5/16” nut driver for drill
Knife
Cable cutter
Wire stripper
Pliers
5/8” end wrench
Voltmeter
Ring pliers

Review barn for the most logical corona line spacing. Use the best-fit possible, balancing between equidistant spacing, and least amount of obstructions.

Attach corona line anchors, turnbuckles, and end insulators to sidewalls



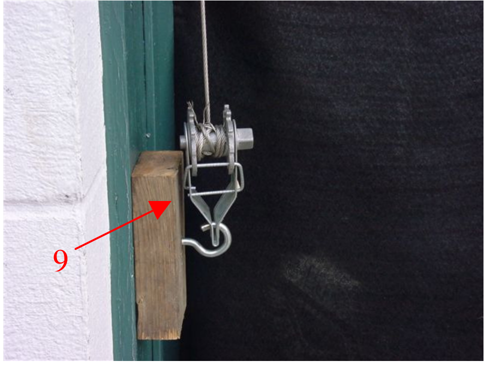
1) Corona line anchors should be screwed into the wall approximately 35 cm down from the ceiling.
2) At the near end of the corona lines, attach a turnbuckle to each anchor.
3) Open the turnbuckle as far as possible.
4) At the beginning and end of the corona line attach an end insulator.
5) Attach a wire rope thimble to the end insulator, on the far end after the corona line.

Attach ground-exciter anchors, springs, and ceiling brackets, and ratchets

6) Ground-exciter anchors should be attached as close to the ceiling as possible on each end of the barn.

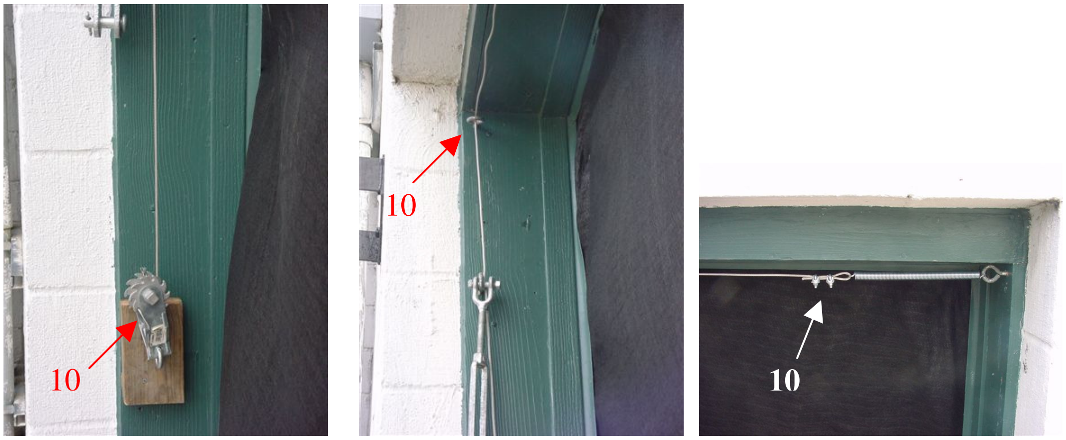
7) Attach a ceiling bracket approximately every 9 meters to the ceiling, in line with the anchors.

8) Attach a spring to each ground-exciter anchor, on the far end of the building.



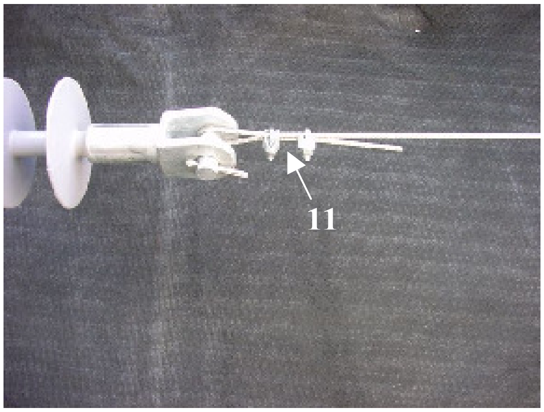
9) At desired height, attach the ratchet to the wall on the near side of the building.

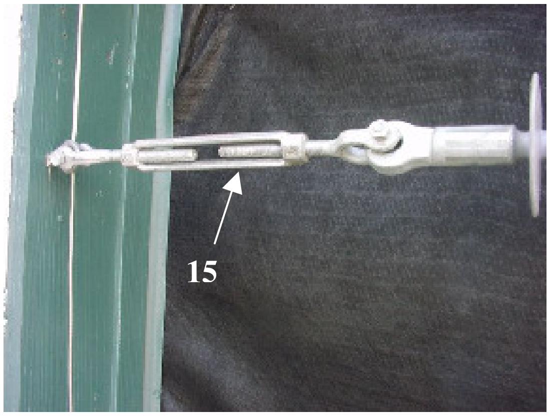
String wire rope between ratchet ground-exciter brackets and anchors for each run



10) String the wire rope through a ratchet, a near anchor, and each in-line ceiling bracket and attach the wire rope to the spring at the far end of the building.

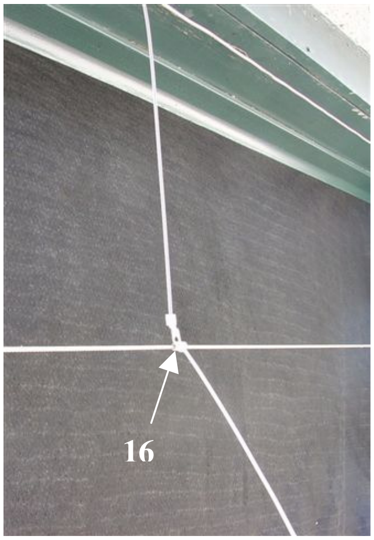
String wire rope between end insulators for each run

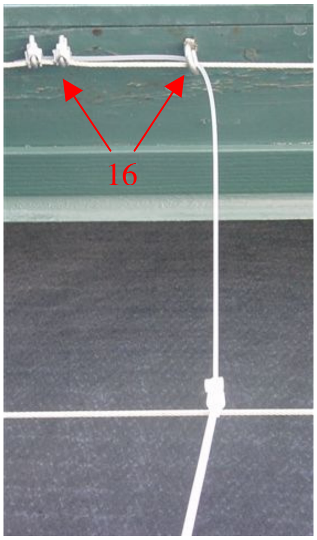


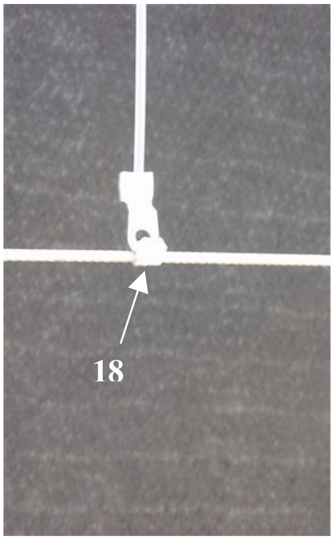


11) Attach wire rope to a near end insulator.
12) String the wire rope to the far end insulator.
13) Before attaching both ends of the wire rope, make sure to prepare and slide insulation tubes in positions where the corona line comes closer than 10 inches (25 cm) from other grounded surfaces such as pipes, electric motors etc. (tubing should extend 12 inches on either side of object).
14) By hand, tighten the wire rope by pulling as much as possible and attach to the end insulator.
15) Tighten the turnbuckle until the wire rope is tight enough to prevent sagging between ceiling insulators (additional tightening can be done at any time).

Attach ceiling insulators to the corona line, then to the ground-exciter wire rope



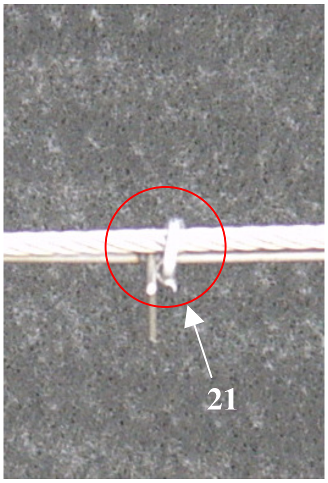


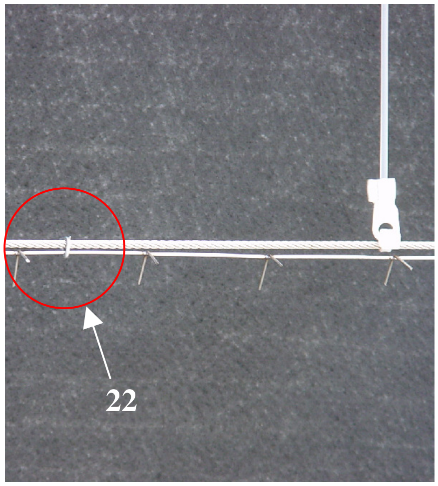


16) Thread a zip-tie through the eyelet of a ceiling insulator and around the corona line. Pull the zip-tie tight.

17) Thread the free end of the ceiling insulator through the ceiling bracket until there is no slack left in the ceiling insulator, and then fix the ceiling insulator to the ground-exciter wire rope using wire rope cable clamps.
18) Trim excess zip-tie tail.
19) Repeat this for each ceiling bracket.

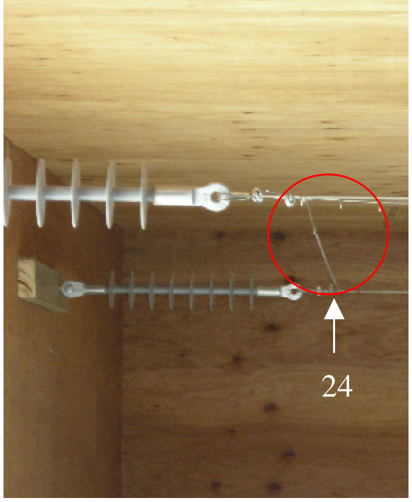
Attach corona points to corona line wire rope





20) With a cage ringer tool, attach the sections of corona points by squeezing a ring around the corona line and the corona points, with the corona point section hanging below the corona line.
21) Use a ring on each end of the corona section and one in the middle of the section, using one ring for each foot of corona points.
22) Corona point sections may be cut to fit short spans, such as the end of a corona line.

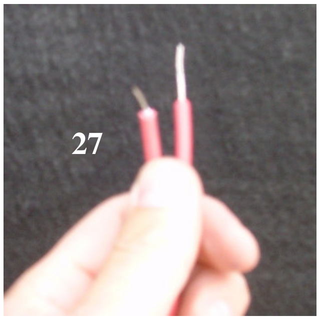
Electrically connect corona point lines in series

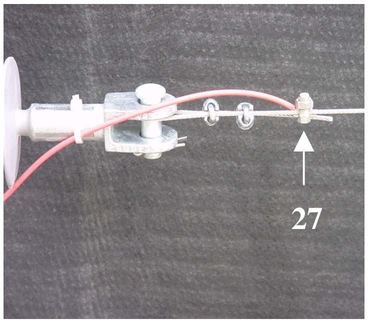


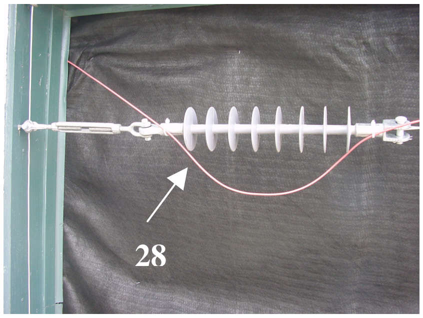
23) In some installations one power supply will power multiple corona lines. In those cases, the corona lines need to be connected together.
24) Using a piece of stainless steel cable and wire rope cable clamps, physically connect the appropriate corona lines.

Attach high-voltage wire to each corona point line to each power supply

25) Install the power supplies in a hallway or office, out of the animal production area, if possible. Use the tabs provided on each power supply to fasten the power supply to the wall.
26) Install the Power Supplies in a cool place, when possible. It is best to be below 70 degrees F (21 degrees C) and space the power supply approximately 1 inch (2 cm) off the wall and at least 4inches (10 cm) between power supplies to allow free air movement.

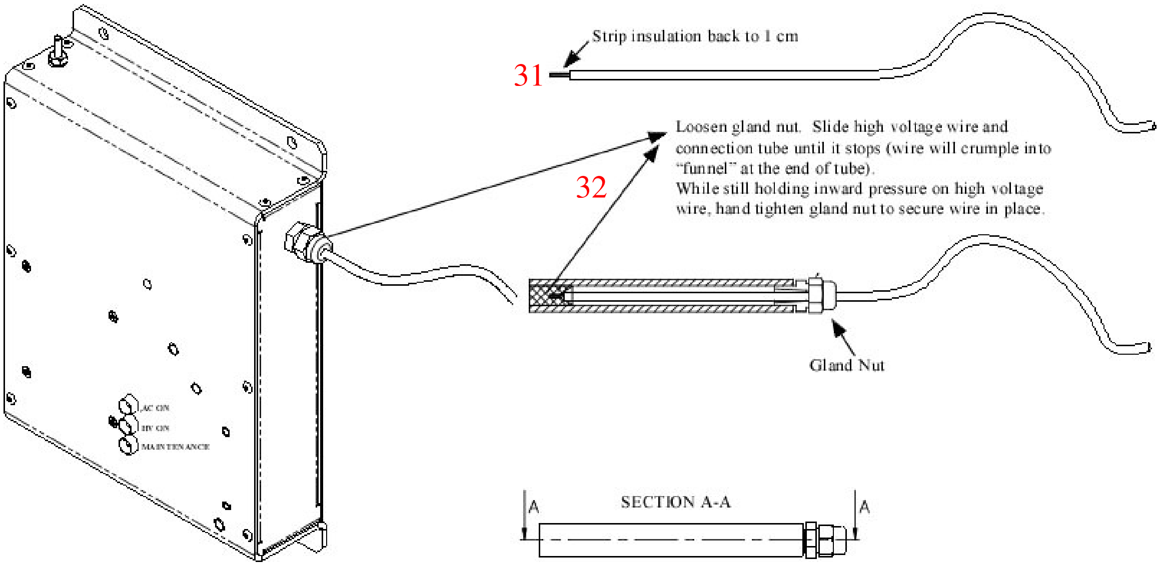






27) Strip the insulation off the end of the high-voltage wire and attach it to the corona line using a split bolt connector.

28) String high-voltage wire from a power supply to its corresponding corona line
29) As desired, straighten and fasten the high-voltage wire back to the power supply.
30) Cut the high-voltage wire to appropriate length, ending at the power supply, leaving at least 30 cm extra.
31) At the power supply, strip the insulation back approximately 1 cm, twisting the strands together.
32) Loosen the gland nut. Slide the high-voltage wire into connector tube until it stops (wire will crumple in "funnel" at the end of the tube). While still holding inward pressure on the high-voltage wire, hand tighten the gland nut to secure the wire in place.



Ground all Equipment

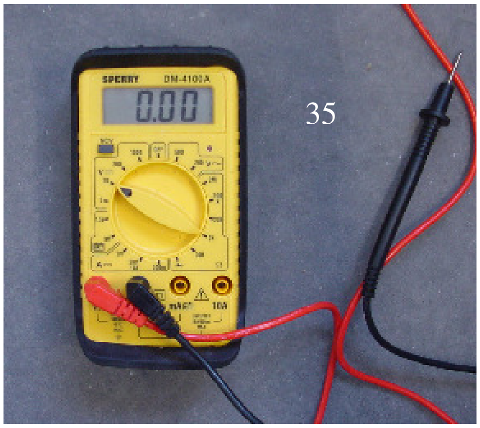
This step is extremely important.

Make sure to ground all other equipment in the barns such a feeders, water supplies, temperature and moisture probes. Typically, equipment suspended by ropes or on plastic pulleys are not grounded. Ungrounded equipment will build a static charge. When touched, the equipment will discharge.

It is of utmost importance to ground the temperature sensor and other sensors that are connected to computer controlled ventilation. **Failure to properly ground the sensors may result in a damaged computer.** These probes often work at low voltage and do not have a ground connection. If a ground wire is present for each sensor, connect all to earth ground. If no ground wire is provided, connect the negative pole of each sensor to earth ground.

Once installation is complete and all grounding is complete, turn the EPI system on to test for ungrounded equipment using a Fluke high voltage probe. The fist test should be at the ventilation computer, make sure the sensors work and that no static charge is building up on the sensor wires. (In some cases, if the sensors are improperly grounded, arcing can be heard from in the computer box, in other cases an alarm may come on. At this point, it is possible the computer is damaged. To avoid this problem, disconnect the sensor wires from the computer (but not earth ground) prior to turning on the EPI system. Measure the static charge on the sensor wires before and after turning on the EPI system. The measured voltage should the same if properly grounded. Then reconnect the sensor wires and test sensors.)

Plug the power supply into a nearby socket



33) Check the lights on the power supply. The green and yellow lights should be on.
34) Check the output voltage and amperage of each power supply using a standard voltmeter on the ports located on the bottom of the power supply.
35) Set the voltage meter to "20 volts", direct current.
36) Locate the "V MON; RET; and I MON" ports on the bottom a power supply.
37) To read the high voltage output: Press the black-probe to the "V MON" port and the red-probe to the "RET" port. The number displayed on the voltage meter is 1/10,000 the actual output voltage. In picture 3, the reading is -3.01 volts, which equals an output of -30,100 volts. -3.01(10,000) = -30,100
38) To read the amperage output: Press the black-probe to the "I MON" port and the red-probe to the "RET" port. The number displayed on the voltage meter is: -0.08 volts, or 0.08 mA. One volt equals one milliamp or 1 Volt = 1mA. 0.08(1) = 0.08

    - Notes:
        - 1 mA = 1/1000 Amp
        - Ohms Law: volts(amps)=watts 30,100(0.00008)= 2.408 watts

39) Adjust amperage to maximum by tightening the ratchet and moving the corona point closer to the ceiling.

Corona Lines
05.06.2008

Appendix D

EPI Operation & Maintenance Manual

Operation and Maintenance of the EPI System

The EPI system discharges negative ions into the airspace inside the bird production area. The ions polarize everything in the airspace, causing particles to attract to a grounded surface. This may be the wall, ceiling, gates, feeders and floors, for example.

There are two cables. The upper cable is a ground plane, the lower cable, the corona line, has corona discharge points attached. Both cables are suspended lengthwise inside the building and each set of cables is roughly equidistant across the width of the building.

The corona point cable (corona line) is energized with a maximum ~30,000 volts of DC power, at a maximum amperage of ~2.0 mA. If the corona line is touched when energized, a shock will occur that is very similar to that from an electric fence. It will hurt, but will not harm you. AVOID TOUCHING THE CORONA LINE WHEN THE EPI SYSTEM IS ENERGIZED.

Understanding the Green, Yellow, and Red lights on the Power Supply

Each power supply has three lights on its face. There is a green light, a yellow light and a red light. The green light indicates that AC power (from the outlet) is reaching the power supply. The yellow light means that high voltage (HV) power is being generated. The red light monitors the amperage (current) output to the corona line.

If the green light is on, electricity is reaching the power supply. If the green light is off, electricity is not reaching the power supply and the power supply will not operate.

When the yellow light is on, it is a good indication that everything is working well.

The red light can be an indicator that the amperage output (current) to the corona line has dropped below the set value. (Note: The red light must be manually set to a known amperage level to be a meaningful indicator of amperage output.) When the red light is on it may mean that the resistance in the corona line has increased or it may mean there is a short-circuit somewhere on the corona line and that the power supply has gone into a mode called Short-circuit Shutdown. [See sections: *When to Adjust the Corona Lines, Short-circuit Shutdown, When to Use Maintenance Adjust,* and *How to Set the Red Light*]

For more detailed information on the exact voltage and amperage levels in the corona lines, readings must be taken from the monitoring ports located on the bottom of each power supply. [See section: *Reading Voltage and Amperage*]

Short-circuit Shutdown

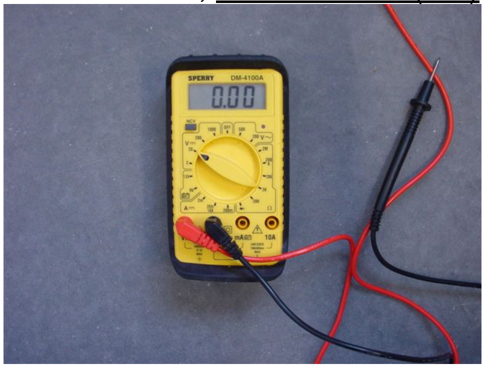
The power supply is designed to shut down if a short-circuit condition occurs. A short-circuit condition may be caused by any contact of a grounded object with the corona point line. The power supply can tell you when a short-circuit occurs: the green “AC” light remains on, the yellow “HV” light will turn off and the red “maintenance light” will turn on. (The green, yellow, and red lights are located on the face of the power supply.)

In the event of a short-circuit, the power supply will attempt to power-up again in approximately 45 to 55 seconds. If the short-circuit is still present, it will not power-up. The green light will remain on, the yellow light will stay off, and the red light will stay on. The power supply will continue to try to power-up every 45 to 55 seconds. The power supply is configured this way to ensure continuously safe operation of the EPI system.

Upon eliminating the short-circuit from the corona line, the power supply will power up. The power supply will return to normal operation: the green light is on, the yellow light is on, and the red light is off.

Reading Voltage and Amperage

- Set the voltage meter to "20 volts", <u>direct current (DC)</u>.



- Locate the "V MON; RET; and I MON" ports on the bottom of the power supply.

- To read the high voltage output: Touch the black probe to the "V MON" port and the red probe to the "RET" port. The number displayed on the voltage meter is 1/10,000 of the actual output voltage. In picture 3, the reading is -3.01 volts, which equals an output of -30,100 volts. -3.01(10,000) = -30,100

- To read the amperage output: Press the black probe to the "I MON" port and the red probe to the "RET" port. The number displayed on the voltage meter is: -0.08 volts, or 0.08 mA. One volt equals one milliamp or 1 Volt = 1mA. 0.08(1) = 0.08.

Notes: 1 mA = 1/1000 Amp
Ohms Law: volts(amps)=watts 30,100(0.00008)= 2.408 watts

When to Use Maintenance Adjust

The maintenance adjust feature on the power supply is an optional feature. This feature, however, can be useful for rapid diagnosis of the amperage (current) reading in each corona line. The amperage level in each corona line will fluctuate depending on how much dust is collected on the objects nearest to it. If the corona line is not adjusted, the more dust on those objects means that the amperage will be a lower value and, conversely, less dust on those objects means that the amperage will be a higher value. A higher amperage level is advantageous for collecting dust from the air.

The maintenance adjust feature allows the red light to be set so it will automatically turn on when the amperage output drops to any level from 2.0 mA down to 0.38 mA. (The red light must be manually set to a known amperage level to be a meaningful indicator of amperage output. See section: *How to Set the Red Light*) For example: Keeping the amperage level output as close to 2.0 mA as possible is advantageous. If the maintenance adjust is used to automatically turn the red light on when the amperage level drops to 1.95 mA, the operator will, at a glance, have very precise knowledge of the amperage level in each corona line.

How to Set the Red Light

To set the red light, locate the tiny screw on the bottom of the power supply. It is accessible through a small circular hole in the aluminum case. Turning the screw clockwise raises the setting and turning the screw counter-clockwise lowers the setting. (The screw cannot be over-tightened and the screw cannot be over-loosened. In other words, it spins in place if adjusted over or under range.)

For example: If the amperage (current) reading of the power supply is 1.99 mA, turning the maintenance adjust screw clockwise until the red light turns on, means that the red light is now set to turn on anytime the amperage output reading is at or below 1.99 mA. If the screw is now turned 360^{O} counterclockwise, the red light will be set to turn on when the amperage output drops to 1.90 mA or below. Each 360^{O} turn of the screw adjusts the setting 0.09 mA. The total adjustable range is 1.62 mA, with an 18-turn pot. It takes 18-360^{O} turns to move from the lowest setting to the highest and vise-versa.

After setting the red light to turn on at the desired amperage output level, the operator, upon seeing the red light on, simply ratchets the corona line closer to the ceiling, one click at a time, until the red light turns off, which in the above example, means the amperage level in that corona line is above 1.90mA. [See Sections: *How to adjust the corona line,* and W*hen to adjust the corona line*]

How to adjust the corona lines

Each corona line is suspended from the ground line running parallel to it. The ground line can be pulled horizontally, using the ratchet at the front end of each line in each barn. Pulling horizontally on the ground line causes the corona line to be pulled vertically.

Wrapping cable onto the ratchet moves the corona line up. Un-wrapping cable from the ratchet allows the corona line to move down.

As dust builds up on surfaces in the barn, each corona line may need to be adjusted closer to the ceiling based on the amperage reading from the power supplies. Using a wrench, turn the ratchet one click at a time until the amperage level has been increased to the desired level (~2mA). [See section: *When to Adjust the Corona Lines*]

Many of the ratchets have a fair amount of tension on them, which takes some effort to overcome. Make sure that while tightening the ratchet that the cable does not become entangled in the gears of the ratchet. In addition, the operator needs to be sure the “stop” of the ratchet seats into the gear to prevent slippage, which can be dangerous because of the tension on the cable.

- Corona line Maximum Adjustment

When adjusting the corona line to increase the amperage, the operator needs to be aware of the maximum setting. The maximum setting is a cable clamp fastened to the cable that prevents further horizontal movement of the ground line. If the operator tries to pull the corona line closer to the ceiling once the maximum setting is reached, damage can be caused to the system.

- Corona line Minimum Adjustment

When adjusting the corona line to decrease the amperage, the operator must be aware of the minimum setting. The minimum is reached when an eyelet, preventing it from moving further, stops a cable clamp on the ground line. The operator must be careful when releasing the cable from the ratchet because of the tension on the ground line. The operator must make sure the “stop” of the ratchet is seated in the gear, before removing the wrench from the ratchet. Allowing the ratchet to freely move from the maximum setting to the minimum setting may cause damage to the system.

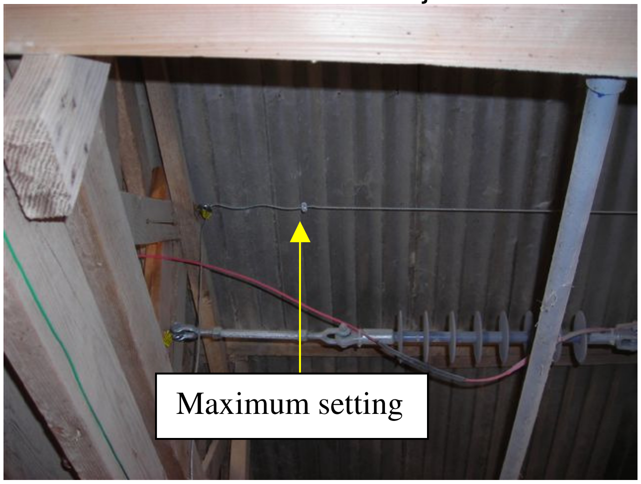
When to Adjust the Corona Lines

Each corona line is adjustable, up or down. Adjusting the corona line up will increase the amperage (current) level in the line. Moving the corona line down will decrease the amperage (current) in the line. There are two reasons the corona lines should be adjusted: the amperage level in the line is too high or the amperage level in the line is too low.

The maximum amperage output allowed by the power supply is ~2mA and the maximum voltage output allowed by the power supply is ~30,000 volts. If the amperage level in the corona line goes above 2mA, the power supply compensates by lowering the voltage in the corona line. For example: A power supply may read 2.04mA and 25,000 volts. This situation indicates that the amperage level is over range and the corona line should be lowered to decrease the amperage demand in the corona line. Lower the corona line until the voltage reads ~30,000 (+/- 1000) volts and ~2.0 (+/- 0.05) mA.

If the amperage level in the corona line is below 2.0 mA, the power supply will always deliver the maximum voltage possible (~30,000 volts) to the corona line. However, keeping the power supply as close to 2mA as possible is advantageous, so the corona line should be raised. For example: A power supply may read 1.80mA and 30,000 volts. This situation indicates that the amperage level is below maximum output and should be increased; therefore, the corona line should be raised to increase the amperage demand in the corona line. Raise the corona line until the amperage reads ~2.0 (+/- 0.05) mA and the voltage is ~30,000 (+/- 1000) volts.

Every corona line has a maximum and minimum adjustment level installed on it.



The maximum setting and minimum setting have been set to allow a limited “safe” range of physical adjustment. The maximum adjustment on the corona line is a cable clamp fastened to the ground line that stops at the eyelet above the ratchet. This prevents the corona line from being pulled up too high, which can break the ceiling insulators or can cause a short-circuit. The minimum is also a cable clamp that prevents the corona line from dropping too low. This prevents the corona line from damage and from a short-circuit. [See section: *How to Adjust the Corona Lines*]

Adjusting the Corona Line between Flocks

After washing down the barn between flocks, the corona line should be lowered to the minimum setting and turned back on. The minimum setting is always the correct place to start when a clean barn is repopulated with birds. It should be noted that not all corona lines, when set to the minimum, are able to achieve 2.0mA and 30,000 volts. In some cases the amperage levels will be over range, and therefore, the voltage level will be below 30,000 volts.

The adjustment range may not always be enough to keep the power supply at 2.0mA and 30,000 volts throughout the entire growing cycle of the birds. However, the adjustment range will increase the maximum effectiveness of the EPI system over a longer period of time.

Regular Observational Maintenance and Recommendations

When walking through the barns on normal daily tasks, it is wise to observe the corona lines. Some basic observational maintenance can help keep the EPI System running smoothly.

- Look for broken ceiling insulators. The ceiling insulators keep the corona line from short-circuiting and do the lifting and lowering of the corona line. If they are broken the chances of problems arising increase. Most ceiling insulators hold the corona line up, but some hold the corona line to the side or down, away from grounded objects. Replace broken insulators as soon as possible.

- Keep the corona points pointing toward the ground. Pressure washing between flocks occasionally causes the corona points to become tangled and point in odd directions. The EPI system works best when the corona points are pointing toward the floor.

- Ground wires are connected to the ratchets, feeder lines, and water lines. All these ground connections are important to the operation of the EPI system. The ground wire attached to the ratchets must be connected to the power supplies. The feeder lines and water lines are grounded via a connection from the center lifting cranks to the upper ground line of the EPI system. These grounds are important for keeping the feeder lines and water lines free of static charges.

- Never wash the power supplies with a pressure washer. The dust accumulation on the power supply needs to be kept clean, but do not use a pressure washer. There is a risk of damaging the power supplies. Use compressed air or a cloth to remove accumulated dust. (Dust accumulation on the power supply may cause it to become too hot, which can cause damage.)

- When washing the barns between flocks always unplug the power supplies to avoid the potential for electric shock.

- When walking past the power Supplies make sure the yellow light is on. If the yellow light is not on and the red light is on then, typically, a short-circuit has occurred. The corresponding corona line should be walked to discover the short-circuit.

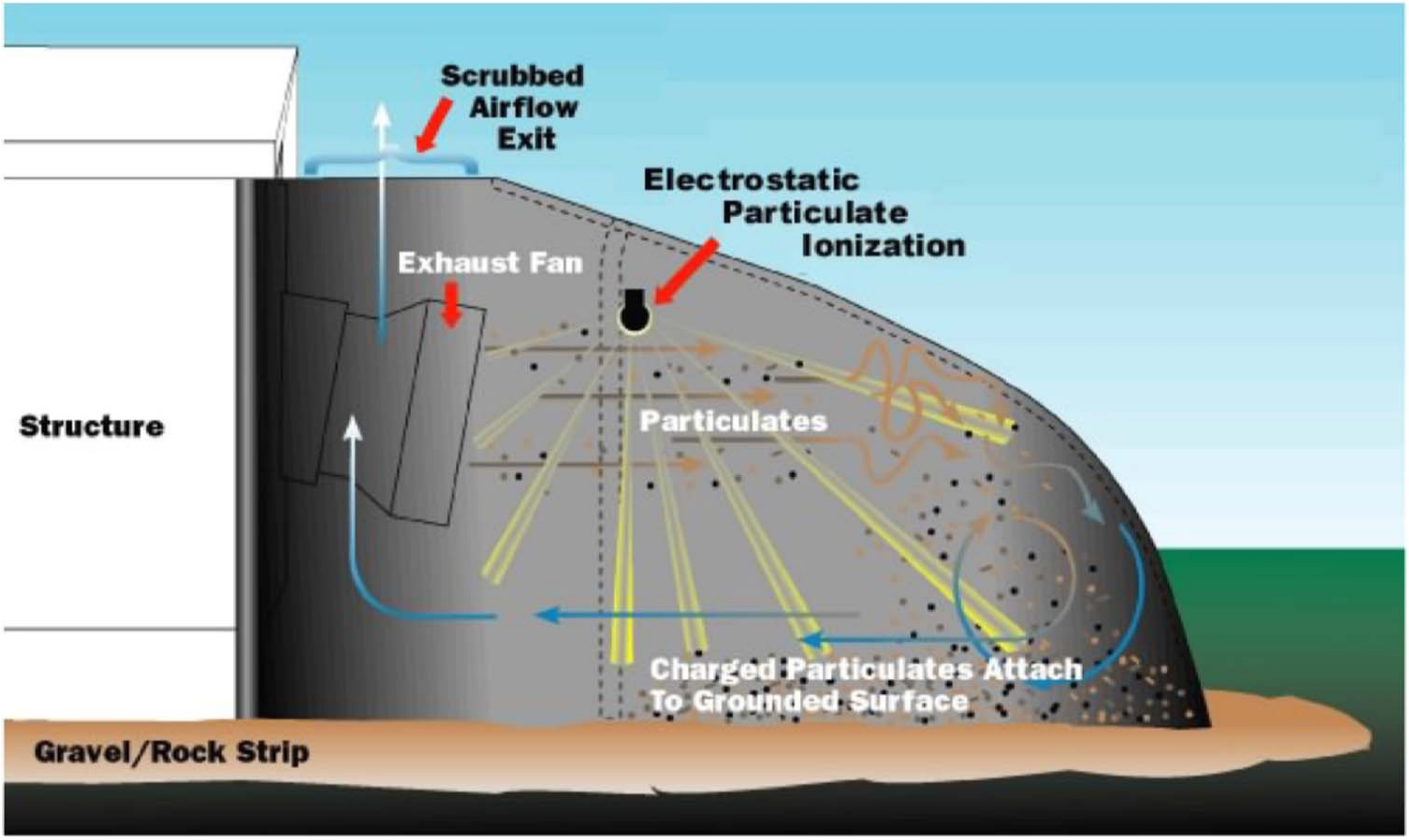
- If no short-circuit is evident; disconnect the HV wire from the power supply (unplug the power supply, loosen the black pressure fitting, and pull the HV wire out). Plug the power supply back in and if all three (green, yellow and red) lights turn on and stay on, then the power supply is functioning properly. Re-check the corona line for a short-circuit.

- If there are no lights on when looking at the power supply, make sure it is receiving power from the outlet. If the outlet has power, and the power supply is plugged in, but no light comes on, then the power supply is broken. If only the green light turns on, the power supply is broken. If only the green light and red light turn on (and no short-circuit is evident) the power supply is broken.

- If all three of the lights are on, and the voltage and amperage readings are "normal" the maintenance adjustment screw should be adjusted to a new setting. [See section: *When to use Maintenance Adjust*]

Appendix E

BioCurtain illustration



How the BioCurtain/EPI Systems Works

Source: Baumgartner Environics, Inc