Texas AgriLife Research
Texas Water Resources Institute

Evaluation of Electrostatic Particle Ionization and BioCurtain Technologies to Reduce Dust, Odor and other Pollutants from Broiler Houses
FY 2010 – Poultry Program
TSSWCB Project No. 10-90

Quarter no. 8 From 12/1/2011 Through 02/29/2012 .

I. Abstract

Project final report was sent to the TSSWCB for review on December 19, 2011.

II. Overall Progress and Results by Task

TASK 1: Project Administration

Subtask 1.1: *TWRI will prepare electronic quarterly progress reports (QPRs) for submission to the TSSWCB. QPRs shall document all activities performed within a quarter and shall be submitted by the 15th of March, June, September, and December. QPRs shall be distributed to all project partners.*

The following actions have been completed during this reporting period:

A. TWRI submitted the seventh QPR for this project on December 15, 2011.

99% Complete

Subtask 1.2: *TWRI will perform accounting functions for project funds and will submit appropriate Reimbursement Forms to TSSWCB at least quarterly.*

The following actions have been completed during this reporting period:

A. Expenditures thus far have totaled $169,258, or about 99% of total project funds have been expended.

99% Complete

Subtask 1.3: *TWRI will participate in meetings as appropriate in order to efficiently and effectively achieve project goals, coordinate monitoring efforts and summarize activities and achievements made throughout the course of this project.*

The following actions have been completed during this reporting period:

A. No need for a meeting this quarter

100% Complete

Subtask 1.4: *TWRI will develop, host and maintain a project website that will be used as a means to disseminate educational materials, project updates and notify readers about educational opportunities.*

The following actions have been completed during this reporting period:

A. The Poultry Odors BMPs website is currently active. It can be found at http://poultrybmps.tamu.edu/. Since the website went online, it has been viewed by a grand total of 87 unique visitors.
B. This quarter, the website was viewed by:
   - 2 unique visitors in December 2011
   - 2 unique visitors in January 2012
   - 4 unique visitors in February 2012

99% Complete

Subtask 1.5: *TWRI will work with project personnel from BAEN and SFA to support the preparation of technical reports as required by project Tasks into published technical reports. These reports will be housed in the TWRI online Reports Database indefinitely.*

The following actions have been completed during this reporting period:

A. Final project report was submitted to the TSSWCB on December 19, 2011.

99% Complete

TASK 2: Quality Assurance

Subtask 2.1: *TWRI, with assistance from BAEN and SFA, will develop a 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 shall be consistent with the guidelines detailed in method specific, peer reviewed or widely accepted documents or SOPs describing the specific methods used. These documents will be detailed in the project QAPP when developed.

The following actions have been completed during this reporting period:

A. This task is complete.

100% Complete

Subtask 2.2: *TWRI will submit revisions and necessary amendments to the QAPP as needed.*

The following actions have been completed during this reporting period:

A. This task is complete.

100% Complete

TASK 3: Poultry Farm Selection and Equipment Installation

Subtask 3.1: *BAEN and SFA will coordinate with TSSWCB to identify and select a poultry operation as a cooperator.*

The following actions have been completed during this reporting period:

A. This task is complete.

100% Complete

Subtask 3.2: *BAEN and SFA will instrument the control and treatment houses with monitoring equipment. This includes air samplers; temperature, humidity, static pressures sensors; and a Fan Assessment Numeration System. Associated data loggers will also be installed.*

The following actions have been completed during this reporting period:

A. This task is complete.

100% Complete

Subtask 3.3: *BAEN and SFA will coordinate with the manufacturer/distributor of the EPI and BioCurtain systems to install both treatment systems in the treatment barn.*

The following actions have been completed during this reporting period:

A. This task is complete.

100% Complete

Subtask 3.4: *BAEN will track the costs associated with the procurement of the EPI and BioCutain systems, the delivery, installation as well as any retrofitting that is needed to make the systems operational. This information will be compiled into a brief, yet all inclusive summary of costs that a producer could expect if this dust and odor mitigation system was purchased and installed.*

The following actions have been completed during this reporting period:

A. This task is complete.

100% Complete

TASK 4: BMP and Monitoring Systems Verification

Subtask 4.1: *BAEN and SFA will test the BioCurtain and EPI systems independently to ensure the proper operation of each system. Testing will occur during two independent one-day trials for each system; one in the summer and one in the winter.*

The following actions have been completed during this reporting period:

A. This task is complete.

100% Complete

Subtask 4.2: *BAEN and SFA will operate and evaluate the EPI and BioCurtain system concurrently to ensure the proper operation of this dual-technology system. Testing of this* *technology will occur over a three-day period and will be repeated once during the summer and once during the winter***.**

The following actions have been completed during this reporting period:

A. This task is complete.

100% Complete

Subtask 4.3: *BAEN and SFA will operate and maintain monitoring equipment in the control barn during all BMP tests to verify that adequate comparisons will be able to be made between treated and un-treated air during a long-term demonstration.*

The following actions have been completed during this reporting period:

A. This task is complete.

100% Complete

III. Related Issues/Current Problems and Favorable or Unusual Developments

- Awaiting TSSWCB decision of funding of Phase II of project so that the fate of the BioCurtain and EPI equipment can be decided. Additional funds will need to be obtained from the TSSWCB for removal of the equipment from the poultry house if Phase II is not funded.
- Currently awaiting review of the project Final Report from the TSSWCB

IV. Projected Work for Next Quarter

- Final report comments addressed and resubmitted to the TSSWCB
- Determine a final disposition for equipment from the project

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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

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.

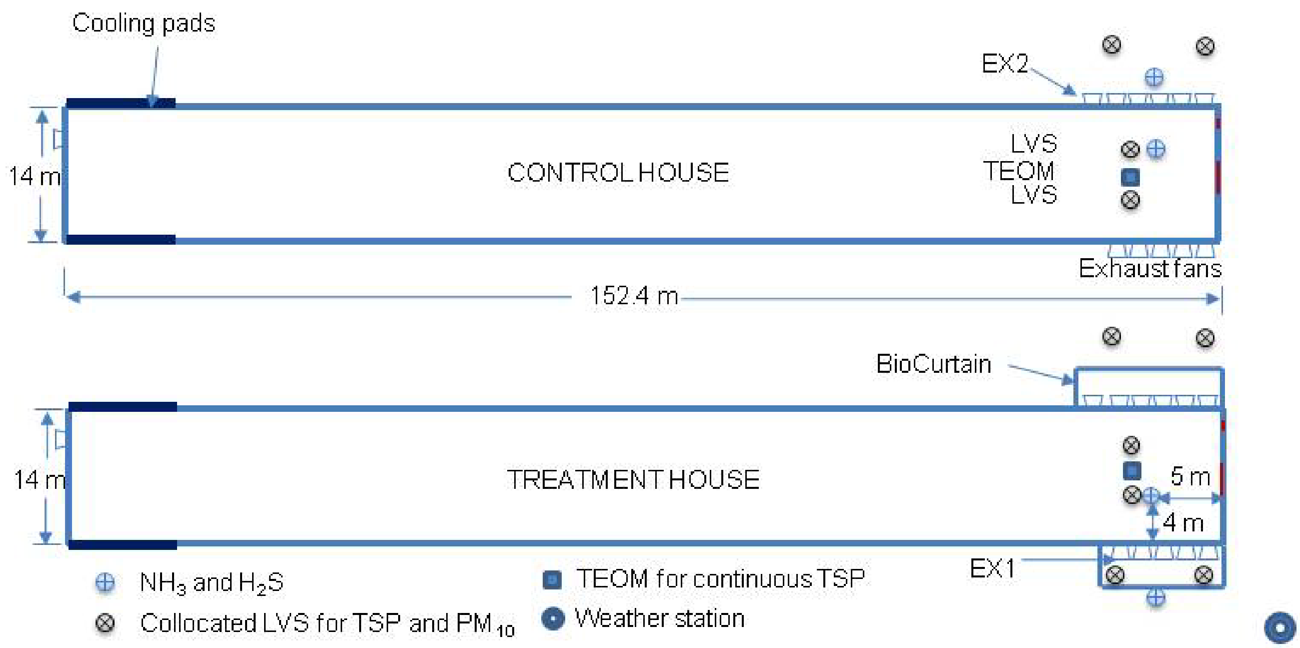

Figure 1. Schematic of the plan view of the broiler houses showing the sampling locations for TSP, PM_{10}, NH_3, and H_2S (not drawn to scale).

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.

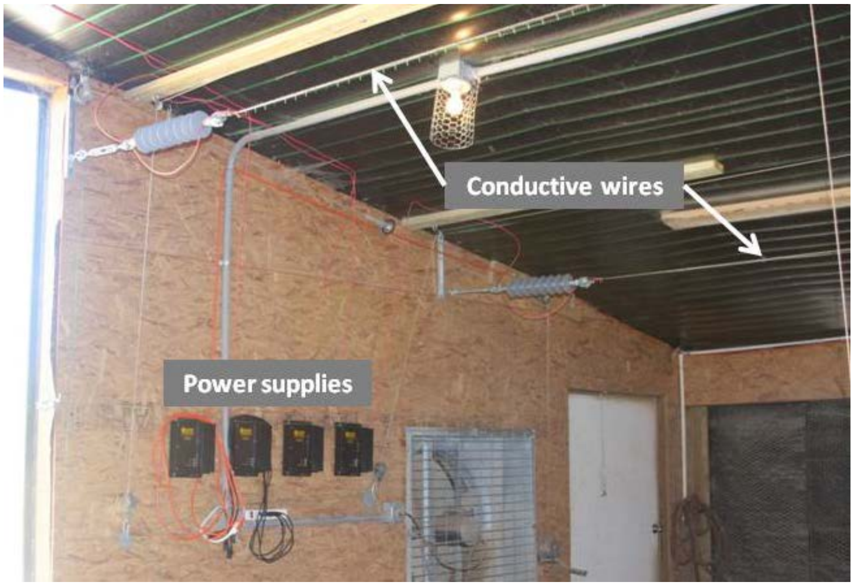

Figure 2. The ionization units hanging from the ceiling of the broiler treatment house and connected to the power supplies.

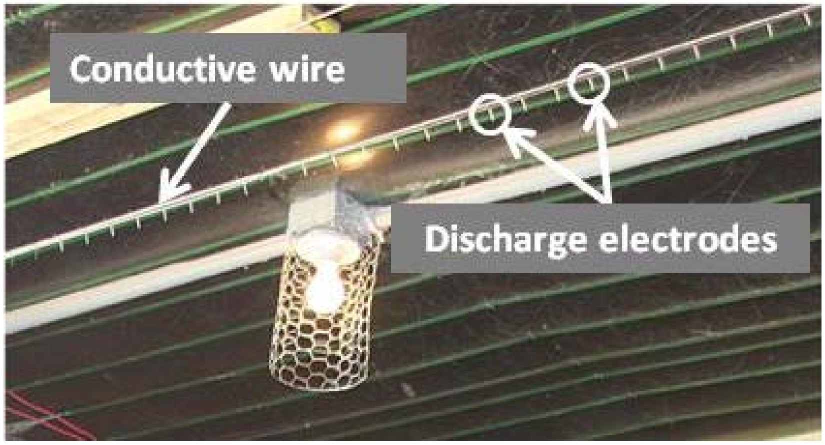

Figure 3. Detail of the discharge electrodes attached to the conductive wire of the EPI™ system.

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.

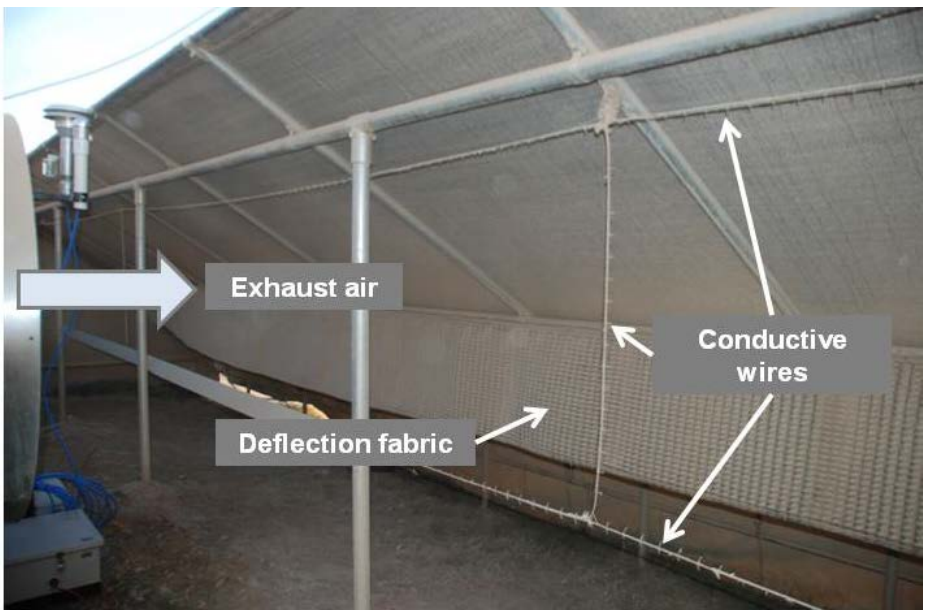

Figure 5. An EPI™ system installed in the BioCurtain™ enclosure to enhance the removal of PM.

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.

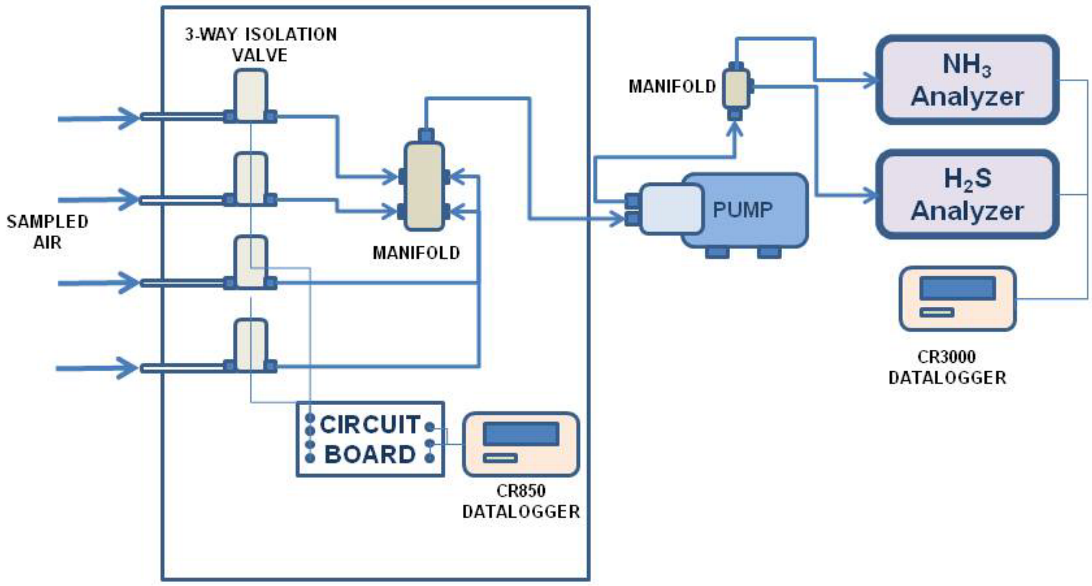

Figure 6. Schematic of the gas sampling system for NH_3 and H_2S.

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

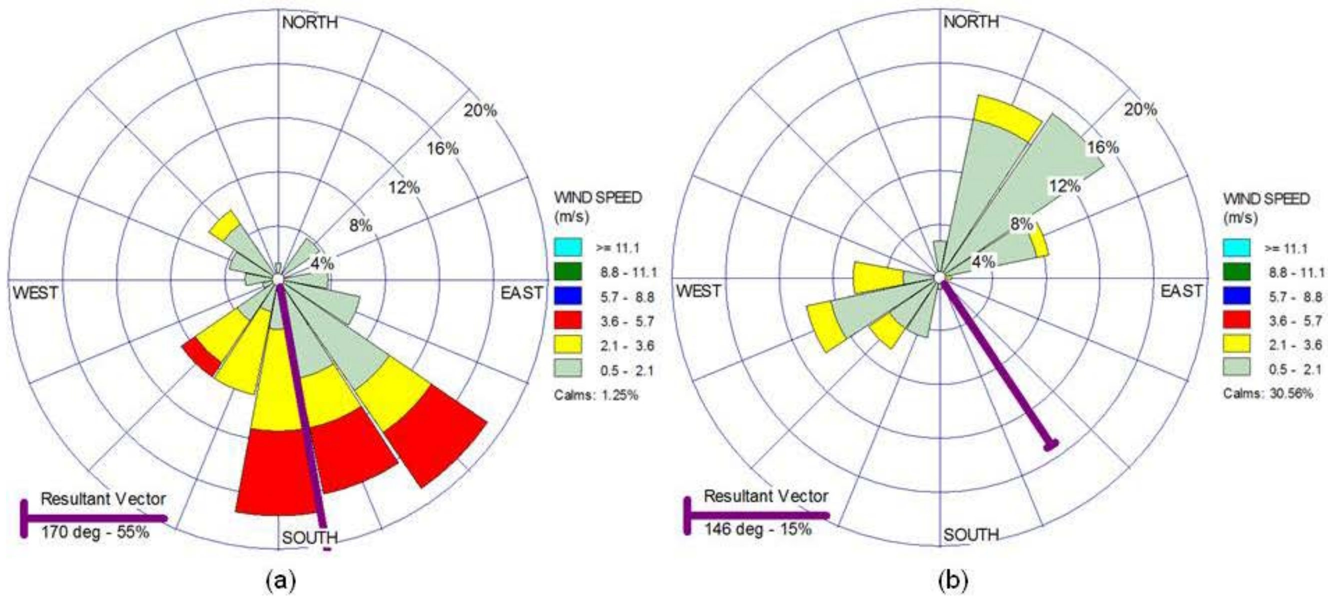

Figure 7. Wind roses during (a) September and (b) December sampling periods. Resultant vectors indicate the mean direction the wind is blowing from and the magnitude of the resultant vector is represented by the frequency count. WRPLOT View version 6.5.1 of Lakes Environmental was used to generate the 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 $\mu g/m^3$) and December (3640 vs. 3620 $\mu g/m^3$). 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).

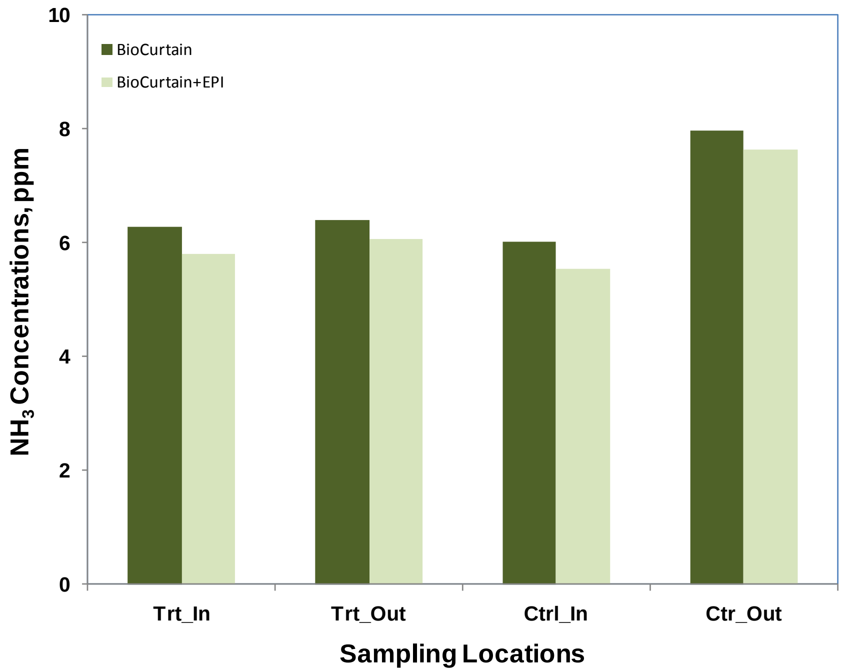

Figure 8. Comparison of the NH_3 concentrations measured in September 2010 when only the BioCurtain™ was in operation and when both the BioCurtain™ and EPI™ are active. The error bars represent the minimum and maximum values. Trt=treatment, Ctrl=control, In=upstream of the exhaust fans, Out=downstream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

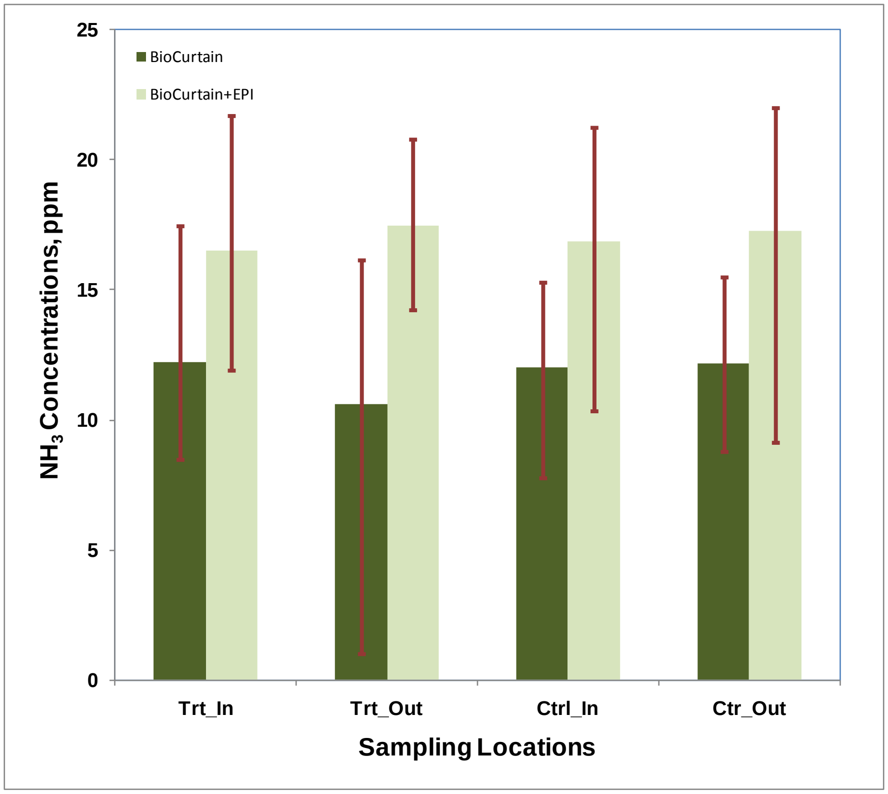

Figure 9. Comparison of the NH_3 concentrations measured in December 2010 when only the BioCurtain™ was in operation and when both the BioCurtain™ and EPI™ are active. The error bars represent the minimum and maximum values. Trt=treatment, Ctrl=control, In=upstream of the exhaust fans, Out=downstream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