A Bio-Aerosol Transmission Test System for Assessment of Electrostatic Particle Ionization (EPI) in Improving Barn Air Quality

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ABSTRACT Removal of bioaerosols has the potential to improve air quality within swine facilities. Bioaerosols consist of various components, including airborne dust and microorganisms. Porcine Reproductive and Respiratory Syndrome Virus (PRRSV) is an example of disease-causing microorganisms that may be transmitted through aerosols. Removal of PRRSV in the air of swine facilities could potentially prevent airborne transmission of the virus to susceptible animals within the swine facility itself as well as to other facilities located some distance away. The Electrostatic Particle Ionization (EPI) has been shown to be effective in removing aerosols from air. A laboratory-scale dual chamber bio-aerosol transmission system has been designed and constructed to conduct experiments to evaluate the performance of the EPI in reducing the PRRSV aerosols. PRRSV is artificially introduced in a (source) chamber. The airflow from the source chamber to the recipient chamber is controlled to simulate aerosol transmission of PRRSV between barns under various atmospheric conditions. Aerosol concentration and particle size distribution, as well as PRRSV loads, can be measured in both chambers to quantify the effectiveness of EPI.

Keywords: Swine Barn, Air Quality, Bioaerosols, Porcine Reproductive and Respiratory Syndrome Virus, Electrostatic Particle Ionization, Negative Ion

INTRODUCTION The term bioaerosols is often used to describe airborne contaminants in swine barns (Lemay and Chenard 2001) due to the presence of viable microorganisms that are potentially
absorbed to the airborne dust (Dennis and Gee 1973 and Seedorf et al. 1998 in Cambra-Lopez et al. 2009). The contaminated air in swine facilities causes respiratory disorder symptoms in both pork producers (Donham and Gustafson 1982 in Tanaka and Zhang 1996) and swine veterinarians (Andersen et al. 2004); for swine veterinarians, longer exposure times were linked to symptoms such as increased phlegm production, airway obstruction, abnormal pulmonary function, and non-prescribed inhaler use (Andersen et al. 2004). For both workers and swine, airborne particles less than five micron in diameter are respirable and can penetrate, deposit, and accumulate in the lungs (Lemay and Chenard 2001, Bundy and Hazen 1973 in Rosentrater et al. 2003). Additionally, respirable airborne dust particles that have absorbed microorganisms or gas molecules pose a greater threat to the respiratory system due to the presence of more than one contaminant (Lemay and Chenard 2001). Aerosol exposure to specific pathogenic microorganisms can also lead to manifestation of respiratory and other diseases in infected swine. Overall, the removal of bioaerosols from the barn air is essential for reducing negative health effects on swine and swine workers.

The Porcine Reproductive and Respiratory Syndrome virus (PRRSv) is an example of microorganisms capable of infecting swine via aerosol or airborne transmission (Cho and Dee 2006 and Dee et al. 2010). The virus causes significant financial losses to the swine industry globally due to decreased growth, increased mortality, and reproductive losses of infected swine (Cho and Dee 2006). Previous studies have shown that the PRRSv is capable of travelling distances of 4.7 km (Dee et al. 2009) and 9.1 km (Otake et al. 2010) downwind from infected swine barns. Therefore, it is important to find means of eliminating or reducing the PRRS in swine barns.

Negative ionization systems are a method of improving air quality within livestock production facilities; the systems release negative ions into the air, which collide with aerosols (dust or liquid) and cause them to become attracted to and subsequently attach to grounded surfaces. Application of a negative ionization system in a laboratory setting resulted in liquid aerosol removal rates that were 8, 9, and 13 times greater than gravitational settling alone when -8 kV, -15 kV, and -20 kV were applied, respectively (Rosentrater 2004). In farrowing and nursery facilities, negative ionization systems significantly reduced respirable, non-respirable and overall dust levels (Rosentrater 2003). Previous studies have successfully shown that negative ionization systems were effective at not only reducing dust concentrations (Mitchell et al. 2004, Richardson et al. 2003a, Richardson et al. 2003b, and Cambra-Lopez et al. 2009), but also ammonia levels (Mitchell et al. 2004), total airborne bacteria (Mitchell and Waltman 2003), and total gram negative bacteria (Mitchell et al. 2004, Richardson et al. 2003a, Richardson et al. 2003b) within poultry houses. Richardson et al. (2003a, b) stated that the reduction of airborne dust due to the negative ionization treatment corresponded with the subsequent reduction in airborne gram-negative bacteria. Overall, the removal of airborne dust could possibly correspond to a health benefit for animals living in facilities due to reduction in airborne transmission of pathogens, such as Salmonella (Richardson et al. 2003b).

Most studies investigating the performance of the negative ionization systems test its effect on airborne bacteria, and few studies can be found on airborne viruses. Since airborne viruses such as the PRRSv as well as Foot-and-Mouth Disease Virus are quite detrimental to the swine industry, research about the ability of negative ionization systems to reduce airborne viruses would greatly benefit the swine industry. The objective of this study is to perform laboratory experiments to (1) evaluate the effectiveness of a negative ionization system, the Electrostatic Particle Ionization (EPI), in reducing airborne PRRSv concentration and transport of PRRSv.
MATERIALS AND METHODS

**Experimental Chambers** Two stainless steel chambers were constructed for conducting experiments. Each chamber was 1.3 m, 1 m, and 1.1 m in length, width, and depth, respectively (figure 1). The frame for the chambers was constructed out of 2 x 4 lumber and plywood sheeting that the stainless steel was then adhered to. The seams of the chambers were sealed with Bondo® putty and then covered with aluminum foil tape. Each chamber has a 61.12 cm x 61.12 cm x 3.18 cm (L x W x D) removable door. The two chambers were connected through a 12.7-cm-diameter galvanized steel duct.

An aerosol mixing box, designed to allow for aerosols to mix prior to entering the chambers, was constructed with 12.7-cm-diameter galvanized steel ducts and was placed at the inlet of the first chamber. A high speed fan (Vortex Powerfan, VTX 800 Series) was installed at the outlet of the second chamber to simulate ventilation in swine barns. The fan is controlled by a rotary potentiometer, which allows for speed adjustments of the fan, thus controlling the airflow rate through the chambers.

High Efficiency Particulate Air (HEPA) filters (61 cm x 30.5 cm) (model no. 01XS-24Z12Z12, Camfil Canada) were installed prior to the aerosol mixing box and the exhaust fan to prevent any unplanned contaminants from entering the test chambers and to filter out contaminants before the air is exhausted. Two furnace filters (61 cm x 30.5 cm) were installed prior to the HEPA filters as prefilters to increase the lifespan of the HEPA filters.

![Figure 1. Experimental chambers assembly](image)

A smoke test was conducted to check for air leakages in the chambers. Since leakages often occur at the fitting joints and seams, a lit smoke pencil was placed near all potential air leakage points to observe the movement of smoke. Silicon sealant and foil duct tape were used to seal up the air leak spots if found. A modified blower door test was also conducted in three different pressure differentials of 20, 30 and 40 Pa to check the air tightness of test chambers. At each pressure level, the voltage applied to the fan and the airflow rate was measured.
**Electrostatic Particle Ionization** The negative ionization system to be tested in the experiments is the Electrostatic Particle Ionization (EPI) manufactured by Baumgartner Envirronics, Inc (BEI) (Olivia, MN). The EPI system consists of corona lines, corona points, insulators, a power supply, and high voltage wire (EPI Air 2013). When the EPI is used in swine facility buildings, the corona lines, which are stainless steel cables, run along the length of the room below the ground plane (i.e. ceiling) and support the corona points (EPI Air 2013). The corona points are pin-like, sharp extrusions that emit negative ions into the air when supplied with high-voltage electricity. The insulators insulate the ceiling and are typically evenly spaced along the corona line. A power supply is used to generate high voltage electricity at low amperage. A high voltage wire is used to connect the corona points to the power supply and the grounded surfaces to ground (EPI Air 2013).

An EPI system is installed in each of the two test chambers in this study (figure 2). A corona line supporting the corona points was attached to the insulators with zip ties. The other end of the insulators was connected to suction cups to suspend the corona lines at the appropriate height within the chambers. A high voltage wire connects the corona points to the power supply and the walls of the chamber to the ground of the power supply. Two of these assemblies were installed per chamber on each side of the duct and parallel to the airflow direction.

![Figure 2a. Corona points, cable, insulators, high voltage wire, and power supply of Electrostatic Particle Ionization (EPI) in experimental chambers](image)

**Aerosol Generation**

![Figure 3. Collison nebulizer and dust generator schematic](image)
Two types of aerosols, liquid droplets containing PRRS virus and swine barn dust, are generated during the experiments. The PRRS virus is a modified live virus from Boehringer-Ingelheim (St. Joseph, MO) that was previously used by other researchers (Dee et al. 2006a, b). The original virus was passaged two to three times and then amplified to the appropriate concentration. A 6-jet Collison Nebulizer (BGI Inc., Waltham, MA) is used to produce PRRS virus aerosols with a mass median diameter (MMD) of 2 µm at an approximated rate of 9 ml/hr. Three concentrations of PRRS virus solutions are aerosolized during the experiments: 1 x 10^4, 1 x 10^5, and 1 x 10^6 plaque forming units (PFU)/ml.

The dust for the experiments was gathered from an existing swine facility. Before experiments, the dust will be autoclaved to kill any viable microorganisms present. A dust generator was utilized to generate a constant flow of dust particles. The dust generator consists of a turntable, a cup, a rotating rod, and a siphon gun. The rod rotates within a cup filled with dust material to allow continuous flow of the dust into grooves within the turntable. The turntable rotates at a predetermined rate to generate a constant amount of dust particles. The siphon gun is operated with compressed air to suck the dust particles from the rotating turntable to generate a constant flow of dust aerosols. Three sets of operating conditions were used to generate three different dust concentrations during the experiments: 1, 2, and 10 mg/m^3.

Both the nebulizer and the dust generator are operated by compressed air, which is filtered by a high efficient in-line filter to remove any impurities in the compressed air (figure 3).

**Aerosol Sampling and Measurement** SKC biosamplers (model no. 225-9594, SKC Inc. Eighty Four, PA) are used to collect airborne PRRS virus. SKC biosamplers are operated with a high-volume sonic flow pump (VAC-U-GO pump) to pull air from the chambers at a flow rate of 12.5 L/min. The biosamplers collect and concentrate the virus aerosols within 20 ml of collection fluid (minimum essential fluid or MEM). After experiments, the collection fluid will be stored in polypropylene plastic containers and frozen at -80 °C for further analysis to quantify the collected virus aerosols. PRRS virus RNA and infectious PRRS virus concentration will be quantified with Polymerase Chain Reaction and plaque assay tests, respectively.

The particle size distribution of aerosols is determined with an optical particle counter (model no. LAP 322, Topas GmbH, Dresden). The device generates a scatter of light signals after its laser beam encounters particles in the incoming air stream, which are then processed to count and determine the aerodynamic diameter of particles in the air (TOPAS 2013).

**Preliminary Calculations** Preliminary calculations were performed to determine the time required to reach a steady state concentration of aerosols in the chambers, which is important as this dictates the amount of PRRS vaccine solution required for each experiment. The flow rate of the fan affects both the time to reach steady state as well as the concentrations of aerosols and virus in the chambers at steady state. The chambers are assumed to have reached steady state when the difference in concentration between the two chambers was only 1% of the theoretical concentration of aerosols at steady state, calculated with the following formula:

\[
C_{SS} = \frac{A}{\dot{V}}
\]

where

- \(C_{SS}\) = concentration of aerosols at steady state (mg/m^3)
- \(A\) = aerosol generation rate of nebulizer (ml/s)
- \(\dot{V}\) = ventilation rate (m^3/s).
The following equations are used to determine the aerosol concentrations in chambers 1 and 2 at specific times:

\[
C_{1n} = \frac{\left( \frac{C_{1n-1} \times V_c + A \times V \times 1}{V_c} \right) \times (V_c - \hat{V} \times 1)}{V_c} \tag{2}
\]

\[
A_2 = \left( \frac{C_{1n-1} \times V_c + A \times 1}{V_c} \right) \times \hat{V} \tag{3}
\]

\[
C_{2n} = \frac{\left( \frac{C_{2n-1} \times V_c + (A_2 \times 1)}{V_c} \right) \times (V_c - \hat{V} \times 1)}{V_c} \tag{4}
\]

where

- \( n \) = time (s)
- \( C_{1n} \) = concentration of aerosols in chamber 1 at time \( n \) (ml/m³)
- \( C_{1n-1} \) = concentration of aerosols in chamber 1 at time \( (n-1) \) (ml/m³)
- \( V_c \) = volume of one chamber (m³)
- \( A \) = aerosol generation rate of nebulizer (ml/s)
- \( \hat{V} \) = ventilation rate (m³/s)
- \( A_2 \) = rate of aerosols exiting chamber 1 and entering chamber 2 (ml/s)
- \( C_{2n} \) = concentration of aerosols in chamber 2 at time \( n \) (ml/m³)
- \( C_{2n-1} \) = concentration of aerosols in chamber 2 at time \( (n-1) \) (ml/m³)

Introduction of liquid droplets (fog) into the chamber will increase the relative humidity in the chambers. The relative humidity of the chambers after liquid aerosolization is calculated to determine if there is a potential for liquid aerosols to condense and form large liquid droplets. Larger liquid droplets have a greater potential to settle due to gravity. There is concern that condensation could affect the ability of experiments to distinguish between aerosol removal due to ionization or due to gravitational settling. Based on the amount of liquid is introduced into a chamber, the following equations are used to calculate relative humidity of the chambers at steady state:

\[
HR_f = HR_i + \hat{A} \hat{V} \rho \tag{5}
\]

\[
RH_f = f(T, HR_f) \tag{6}
\]

where

- \( T \) = temperature initially prior to experiments (˚C)
- \( HR_i \) = humidity ratio at steady state concentration of aerosols (g water/kg dry air)
- \( HR_f \) = initial humidity ratio prior to experiments at temperature \( T \) (g water/kg dry air)
- \( \hat{A} \) = aerosol generation rate (ml/s)
- \( \hat{V} \) = ventilation rate of fan in m³/s
- \( \rho \) = density of water at temperature \( T \) in kg/m³.
Once the temperature and humidity ratio are calculated, the final relative humidity is determined with a psychometric chart.

**Experimental Procedure** Each experiment involves four stages consisting of different steps. In the first stage, the nebulizer and/or dust generator will generate aerosols until the aerosol concentrations reach steady state. During the second stage, the SKC biosamplers will collect airborne PRRS virus and the optical particle counter will determine the particle size distribution of aerosols within both of the chambers. After sampling is completed, the EPI is initiated and aerosols are allowed to reach steady state under ionization treatment. Sampling of airborne virus and aerosol particle size distribution will occur again to determine the reduction due to ionization treatment.

**PRELIMINARY RESULTS** The test chambers performed well in terms of air flowrate control. The flowrate varied linearly with the voltage applied to the fan motor (figure 4). This indicates that a range of airflow rates may be achieved precisely by controlling the fan voltage using a rotary potentiometer.

![Figure 4](image-url)

**Figure 4.** Variation of airflow rate through test chambers with applied voltage to fan motor

The time required for aerosol concentrations to reach steady state for various ventilation rates of the fan are shown in figure 5. The resulting curve has a power function related directly to the flow rate. As the flow rate increases, there is a general decrease in time required to reach steady state. Additionally, table 1 displays the liquid aerosol concentration at various ventilation rates. Generally, as ventilation rate increases, the liquid aerosol concentration at steady state decreases.

![Figure 5](image-url)

**Figure 5.** Time for liquid aerosols to reach steady state according to ventilation rate of fan.
Table 1. Steady state concentration of aerosols according to ventilation rate

<table>
<thead>
<tr>
<th>Ventilation Rate</th>
<th>Aerosol Steady State Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>m³/min</td>
<td>ml/m³</td>
</tr>
<tr>
<td>0.5663</td>
<td>0.2613</td>
</tr>
<tr>
<td>0.8495</td>
<td>0.1738</td>
</tr>
<tr>
<td>1.1327</td>
<td>0.1297</td>
</tr>
<tr>
<td>1.4158</td>
<td>0.1034</td>
</tr>
<tr>
<td>1.699</td>
<td>0.0859</td>
</tr>
<tr>
<td>1.9822</td>
<td>0.0734</td>
</tr>
<tr>
<td>2.2653</td>
<td>0.0639</td>
</tr>
<tr>
<td>2.5485</td>
<td>0.0566</td>
</tr>
<tr>
<td>2.8317</td>
<td>0.0508</td>
</tr>
</tbody>
</table>

Aerosolization of liquid aerosols into the air at 25 and 20°C would only increase relative humidity by 1.25 and 2%, respectively (Table 2). It is unlikely that the relative humidity increase due to aerosolization of liquid during the experiments will cause condensation of liquid aerosols. Therefore, increase in gravitational settling of liquid aerosols should not be a concern if the initial relative humidity within the trailer is controlled and maintained at an acceptable level.

Table 2. Relative humidity increase at steady state concentration of liquid aerosols for a ventilation rate of 0.0094 m³/s and moisture flow rate of 0.0025 g/s.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Relative Humidity</th>
<th>Humidity Ratio</th>
<th>Humidity Ratio</th>
<th>Relative Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>degrees C</td>
<td>%</td>
<td>gram water / kilogram air</td>
<td>gram water / kilogram Air</td>
<td>%</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>7.3</td>
<td>7.52</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>8.75</td>
<td>8.97</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>10.25</td>
<td>10.47</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>11.75</td>
<td>11.97</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>13.25</td>
<td>13.47</td>
<td>92</td>
</tr>
<tr>
<td>25</td>
<td>50</td>
<td>10</td>
<td>10.22</td>
<td>51.25</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>12</td>
<td>12.22</td>
<td>61.25</td>
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<tr>
<td></td>
<td>70</td>
<td>14</td>
<td>14.22</td>
<td>71.25</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>16</td>
<td>16.22</td>
<td>81.25</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>18</td>
<td>18.22</td>
<td>91.25</td>
</tr>
</tbody>
</table>
SUMMARY

Test chambers were constructed for the purpose of evaluating the performance of the EPI in reducing the concentration and transport of PRRSv. Preliminary calculations and tests were performed to quantify:

- The variation of airflow rate due to applied voltage of the fan motor.
- The time to reach steady state concentration of aerosols due to different airflow rates.
- The aerosol steady state concentration for different airflow rates.
- The relative humidity increase due to aerosol generation at different airflow rates.

The quantification of such parameters allows for the proper simulation of aerosol transmission of PRRSV between barns.

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