Evaluation of a Pilot-Scale Electro-nanospray System for Decontaminating Pig Barns

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Exposure to bioaerosols, noxious gases, and high dust concentrations in confined livestock facilities have been linked to human and animal health hazards, with consequent adverse economic implications. Having a safe and secure workplace is essential for hog operations, and necessitates the need for enhanced strategies to address the concerns due to air contaminants in production facilities. In this study, an electro-nanospray system was developed for pig barn decontamination. This technology generates engineered water nanostructures (EWNS) through electrospraying and ionization of reverse osmosis (RO) water. The highly charged nano-scale water droplets encapsulate reactive oxygen species (ROS), which are responsible for bacterial inactivation and for capturing particulate matter through electrostatic forces.

The size of generated EWNS is dependent on the liquid electrical pH and conductivity, liquid flow rate, applied voltage, distance between needle tip and counter electrode, and needle diameter. These nanodroplets are highly mobile and can remain suspended in the air for hours colliding with particulate matter in the air, effectively removing dust from the air through Coulomb interactions. The oppositely charged dust and water droplets attract each other, resulting in the deposition to surfaces through gravitational force. Due to the highly reactive oxygen species (ROS) encapsulated in the EWNS, it can deodorize compounds through various chemical reactions, while ROS such as hydroxyl radicals, superoxide, and hydrogen peroxide cause oxidative stress, damage cell membranes and lipoproteins through lipid peroxidation, resulting in microbial deactivation. Aside from the previously mentioned advantages, electrospray is environmentally benign and safe due to the absence of chemical residues.

Studies on the application of electrosprays in decontaminating animal facilities are limited and not fully established. Recently, laboratory scale studies optimizing the operating parameters of the electro-nanospray system for the inactivation of surface and air contaminants relevant to livestock operations showed the importance of design parameters such as increasing the distance of the capillary needle, liquid flow rate, pH, and conductivity could increase the electrospray area. However, other operating conditions in livestock stock facilities require further examination, including the number of EWNS generators, higher ventilation rate, relative humidity (RH), dust and bioaerosol concentrations, and effect on diverse contaminants.

Project motivation and knowledge gap

Existing electrospray technology developed by various researchers provided a clearer understanding of its mechanism and applications on surface and air decontamination. However, the effects of the electrospray system generating nano-scale water droplets in inactivating airborne bacteria, reducing dust and noxious gases, and decontaminating surfaces in actual livestock barns are not yet tested. Therefore, this project aimed to further refine and evaluate the performance of an electro-nanospray system in improving air quality and decontaminating surfaces in a swine barn, specifically looking at variations in ventilation rate, the number of needles, higher relative humidity, higher dust and bioaerosol concentrations, and different contaminants.

> "The electro-nanospray system effectively reduces levels of bacteria, gases and dust."

The objective of the work was to design and investigate the effectiveness of the electro-nanospray system in decontaminating a small pig room. Specifically, this study aimed to:

1. Determine the decontamination performance under a broad range of operating parameters such as airflow rate and number of spray injectors in laboratory-scale chamber;
2. Evaluate the performance of the electro-nanospray system in inactivating airborne bacteria, reducing gases and dust levels in small-scale pig rooms; and
3. Evaluate the performance of an electro-nanospray system in decontaminating barn surfaces.

Laboratory-scale evaluation

Prior to testing the nanospray under actual swine barn environment, laboratory-scale experiments on bioaerosol deactivation were conducted using an acrylic chamber in which the electro-nanospray system was installed. A series of experiments were conducted wherein Escherichia coli was dispersed as test bioaerosol pathogen inside the chamber and the resulting E.coli deactivation efficacies were determined at varying number of EWNS needle spray injectors and bioaerosol concentrations. The test chamber was also used to conduct experiments to determine the effect of the nanospray on decontamination of various types of surfaces commonly found in hog production facilities such as plastic, metal, wood, and concrete.

In-barn assessment

In this study, an electro-nanospray system generating engineered water nanostructures (EWNS) was designed and tested to reduce microorganisms in air and on surfaces and airborne particulate matter in a swine barn room. The electro-nanospray system was enclosed in an acrylic treatment chamber and installed in one of the two pilot-scale rooms (Control vs. Treatment) at Prairie Swine Centre, with four grower/finisher pigs per room. Over the 8-week trial, air samples were collected to evaluate the impact of the electro-nanospray system on levels of airborne dust and bacteria, gases (i.e., ammonia, hydrogen sulphide, carbon dioxide, ozone) and microbial population on various types of surfaces, including concrete, wood, polycarbonate plastic and stainless-steel metal. Three replicate trials were conducted.

Operating conditions were optimized in the previously conducted laboratory-scale study. All other design and operating parameters are the same as those determined from the laboratory scale experiment. In the treatment room, the contaminated air from the room was drawn into treatment chamber and subjected to the EWNS generated by the electro-nanospray system installed in the chamber, and the treated air was recirculated back to the room airspace. Thus, the continuous flow of room air into the electro-nanospray treatment chamber resulted in continuous partial cleaning of the air in the overall room airspace through recirculation of treated air to mix with the bulk air in the room airspace.

Monitoring was initiated during the first two weeks of the trial to collect baseline data, after which treatment was applied by turning on the electro-nanospray treatment system from 3rd to 7th week, at which time the electro-nanospray system was turned off. Then, monitoring was continued for another week to determine any residual effect of the treatment on room air quality. Air samples were collected 0.6 m away from the exhaust at 1 m above the pigs.

Results

Theoretical calculations done as part of the laboratory assessment revealed that the optimum air flow rate was 10 ACH, resulting in 49% microbial reduction using E. coli as test pathogen. Considering this deactivation efficiency, the optimum number of spray injectors for the volume of 0.25 m3 treatment chamber used is 16. Furthermore, it was observed that higher reduction efficiency could be achieved at higher bioaerosol concentrations, wherein 1.3 x 105 colony forming units (CFU) per m3 achieved the highest reduction efficiency at 61% after an hour of treatment using the optimized operating conditions. Surface decontamination tests using laboratory-scale set-up to apply the EWNS nanopsray on various surfaces such as stainless-steel metal, polycarbonate plastic, slab wood, and concrete showed 71%, 64%, 59%, and 51% microbial reduction, respectively.

The optimized and designed electro-nanospray system was installed in a small pig room at PSC with four grower/finisher pigs. One electro-nanospray system was installed during the preliminary trial, and two units were installed in pilot-scale trials. Results from the preliminary trial with one electro-nanospray system showed no measurable impact on culturable bacteria, and hydrogen sulphide; however, an average reduction of 28% and 80% was observed for dust and ammonia concentrations. Various in-barn surfaces such as concrete, stainless-steel metal, polycarbonate plastic, and wood slab resulted in surface microbial reduction of 32%, 26%, 22%, and 19%, respectively. Pilot-scale experiments with two electro-nanospray systems installed showed better results on culturable bacteria and dust concentrations with 31% and 42% reduction efficiency, respectively. Moreover, surface decontamination revealed 46%, 36%, 31%, and 29% microbial reduction on concrete, stainless-steel metal, slab wood, and polycarbonate plastic surfaces, respectively. On average, a reduction of 40% in ammonia concentrations was observed, which was relatively lower than the preliminary trial results, mainly due to differences in environmental conditions when the trials were performed (summer vs. winter conditions). Only 6% reduction in hydrogen sulphide was observed. Pig performance showed no significant difference between the Control and Treatment rooms.

Conclusions

Overall, the electro-nanospray system can provide an innovative approach to mitigating air quality as it can reduce levels of bacteria, dust, and gases. In addition, no chemical residues remain; thus, it can be a sustainable and environment-friendly treatment technology for barn air and surface decontamination.

Results from this study effectively reduced microorganisms in the air and on surfaces. Although EWNS can potentially deactivate gram-negative bacteria such as E. coli, further investigation of other susceptible microorganisms in the barn that can be deactivated by this technology should be identified, and the performance in deactivating infectious, transmissible pathogens of concern to the swine industry, such as PRRSV should be investigated in future work.

The effects of the electro-nanospray technology when applied in larger-scale swine rooms over a longer period should be evaluated. To assess the overall health impact, we need to analyze the effects on lung function and respiratory system of pigs after exposure to EWNS. After which, a feasibility analysis for implementation of this treatment technology in commercial livestock facilities should be conducted.