EVALUATION OF A SPRINKLER COOLING SYSTEM ON INHALABLE DUST AND AMMONIA CONCENTRATIONS IN BROILER CHICKEN PRODUCTION

by

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

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To my husband and our families, thank you for the constant love and support.

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ABSTRACT

Indoor air contaminants such as dust and gases are present in concentrations that may be hazardous to worker health in poultry production. Poultry dust may contain inflammatory agents (*e.g.*, endotoxin) and inhalation exposure has been associated with pulmonary symptoms. The current control practice to reduce worker exposure to poultry dust is the use of respiratory protection (*e.g.*, filtering face-piece respirators). Limited research has been conducted to evaluate engineering controls to reduce dust concentrations in broiler chicken production. Therefore, the purpose of this research was to evaluate the effectiveness of a water sprinkling system to reduce inhalable dust and ammonia concentrations in a broiler chicken house.

Inhalable dust and ammonia concentrations were measured daily for the production cycle of a flock of broiler chickens (63 days). Inhalable dust was measured gravimetrically using an inhalable sampler and ammonia was measured by a direct reading sensor. Sampling was performed on a stationary mannequin inside two broiler chicken houses. One house used a sprinkler cooling system to deliver a water mist throughout the house and the second house was an untreated control. The sprinkler system activated after day 5 of chicken placement and continued through day 63 of the broiler chicken production cycle. The following sprinkler activation program was used each hour from 6am to 10pm: days 5–9 five seconds, days 10–14 ten seconds, and days 15-63 for fifteen seconds.

Geometric mean (GM) inhalable dust concentrations collected in the treatment house (5.2 mg/m^3) were lower than those found in the control house (6.0 mg/m^3). The GM ammonia concentration within the treatment house was higher at 10.6 ppm (GSD:

1.80), compared to the control house (GM 9.51 ppm; GSD: 1.77). However, the observed differences were not statistically significant ($p = 0.33$ and $p = 0.34$, respectively).

Concentrations of inhalable dust were reduced by 11% when using the water sprinkling system, however the reduction was not statistically significant. The observed reduction in dust concentration was not sufficient to eliminate the need for respiratory protection.

PUBLIC ABSTRACT

Workers are exposed to dust and gases in broiler chicken production during daily work activities. These hazardous contaminants are caused from inadequate ventilation and have been associated with decreased lung function. Currently, workers protect themselves by using respirators; however, respirator use in agriculture is relatively low. Therefore, more protective controls should be considered.

The purpose of this study was to evaluate a water sprinkling system that is typically used for thermal stress in broiler chicken production. Concentrations of dust and ammonia were compared within a house equipped with the sprinkling system and one without. Sampling occurred throughout the production cycle (63 days) of one flock of chickens. The sprinkler activated on day 5 and continued throughout day 63; water was released periodically from 6 am to 10 pm and the amount of water increased at day 10 and 15.

Dust concentrations were reduced by 11% when using the water sprinkling system. Although dust concentrations were reduced, the difference was not significant and ammonia concentrations were not reduced. Therefore, workers within the broiler chicken houses are encouraged to continue using respirators when completing daily work tasks.

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LITERATURE REVIEW

Broiler Poultry Production

Global broiler chicken production has exceeded 80 million pounds each year since 2011; broiler chickens are birds raised specifically for meat production (The Poultry Site, 2014). The United States (U.S.) and Asia have the largest broiler industries, producing 75% of the world's chicken meat (The Poultry Site, 2014). These numbers are expected to grow as populations increase, especially in developing countries. Chicken meat represents approximately 88% of the global poultry meat output and nearly 40 billion pounds of chicken meat is produced each year in the U.S. alone (The Poultry Site, 2014; USDA Economic Research Service, 2012). Approximately 40 companies are involved in the business of raising, processing and marketing broiler chickens in the U.S.; these companies directly and indirectly employ approximately 500,000 Americans, including those working at family farms (National Chicken Council, 2012).

The production buildings are designed to provide optimal conditions for broiler chickens to grow; in these operations, chickens are floor-housed. Production length for broiler chickens, from chick placement to harvest, can range from 28-63 days; broiler production is completed year round (MacDonald, 2008). Depending on the geographic location of the house, either natural ventilation or mechanical air movement by fans is used. Modern poultry farms producing broiler chickens commonly use mechanical ventilation systems and rely on: the number of fans, air inlet and outlets, and controls to regulate fan operation (Bustamante et al., 2013; Aviagen, 2003). During the production cycle, workers are responsible for tracking growth, maintaining environmental conditions in the house, removing deceased birds, and maintaining equipment (Cobb, 2008). Upon harvest date, workers remove birds, till the poultry house bedding to redistribute, and de-cake the floor litter and/or remove existing litter (Aviagen, 2003).

Exposure in the Work Environment

Broiler chicken workers are exposed to inorganic and organic dust as well as ammonia and microorganisms (Viegas et al., 2013). Poultry dust is composed of feces and uric acid, feathers, bacteria and fungi; these contaminants thrive in the poultry litter environment (Viegas et al., 2013; Nonnenmann et al., 2010). Contaminant concentrations are typically higher at the end of the growth period as a result of increased fecal and urine biomass and feather debris as birds grow (Lawniczek-Walczyk, 2013).

Dust concentrations in poultry houses vary; one study reported that inhalable dust concentrations ranged from 0.02 to 81.33 mg/m^3 and respirable dust concentrations as high as 6.5 mg/m^3 (Ellen et al., 2000). Factors affecting these concentrations are: age of animal, animal activity, bedding materials and season. The most important sources of dust seem to be the birds and their excrements (Ellen et al., 2000).

In general, dust concentrations are higher in poultry operations that house birds on the floor compared to those that house birds in cages. Geometric mean inhalable dust concentrations for floor-housed operations in a U.S. poultry operation were 24 mg/m^3 (Lenhart et al., 1990) and 21 mg/m^3 in an operation in Iran (Golbabaei and Islami, 2000). Inhalable dust measurements in floor operations at a site in Europe ranged from 8 to 9 mg/m^3 (Linaker and Smedley, 2002). In facilities where birds are housed in cages, total dust concentrations are considerably lower, levels at sites in Europe ranged from 1 to 4 mg/m^3 in caged operations (Clark et al., 1983; Takai et al., 1998). Similarly, at sites in the United Kingdom (UK), respirable and inhalable dust concentrations are significantly higher in floor-housed broiler operations compared to cage operations (Wathes et al., 1997).

Workers in floor-housed poultry operations have greater exposures to total dust and ammonia than workers in caged or perch style operations (Kirychuk et al., 2006). However, Kirychuk et al. (2006) reported that individuals working in cage-housed poultry operations reported a higher frequency of current and chronic symptoms. High concentrations of endotoxin were found in facilities with low total dust concentrations; endotoxin is a toxin produced by certain bacteria and is released when the bacterial cell is destroyed (Kirychuk et al., 2006). Endotoxin is associated with the reported symptoms of "phlegm," which may explain why cage-housed workers reported pulmonary symptoms. This association suggests that reducing exposure to endotoxin may decrease pulmonary symptoms experienced by workers.

An international study found that workers involved in broiler chicken production were exposed to increasing concentrations of inhalable dust, respirable dust, and endotoxin as broilers aged (Oppliger et al., 2008). Workers involved in catching mature broilers at the end of the production cycle were exposed to inhalable dust concentrations of 37.6 mg/m^3 and average endotoxin concentrations were 6198 EU/m^3 (Louhelainen et al., 1987). This information suggests that workers have an increased risk of inhalation hazard as chickens become larger toward the end of the production cycle. Therefore, respiratory protection for workers involved in broiler chicken production is needed, especially during the latter weeks of the production cycle.

Health Effects from Contaminants

In recent years, attention has been given to evaluating exposures in large-scale farming operations and associated health effects among workers in these operations, particularly the swine industry. However, less research has been conducted within other agriculture sectors that specialize in animal production, such as the broiler chicken industry. As demands for meat increase worldwide, large-scale broiler chicken production continues to increase. Workers in broiler chicken production are exposed to inhalation hazards, including bioaerosols, microbial components; dust and other volatile compounds, such as ammonia and hydrogen sulfide (Hribar, 2010; Brodka et al., 2012). Therefore, determining effective methods to control these inhalation hazards is important. Exposure reduction is needed to prevent inhalation exposure, associated pulmonary symptoms and disease; the workers in this growing business are essential to meat production in the U.S.

Individuals involved in animal production display a higher prevalence of adverse respiratory systems than other farmers and rural residents (Kogevinas et al., 1999; Radon et al., 2001; Rimac et al., 2010). This could be due to inhalation of environmental contaminants; specifically, inhalation exposure to poultry dust has been associated with respiratory symptoms and lung diseases among agricultural workers, including broiler chicken production workers (Iversen et al., 2000; Alencar et al., 2004). Because mold and mites thrive in the poultry litter environment, workers may also present with sensitization allergic reactions to mold and/or dust mites (Rimac et al., 2010).

Individuals involved in agriculture have presented with decreased pulmonary function after completing tasks in their work environment (Donham et al., 2000;

Kirychuk et al., 2003; Radon et al., 2001). Specifically, research suggests that poultry workers have lower lung function than swine workers and factors related to work are associated with this decreased lung function (Radon et al., 2001). Additional symptoms such as phlegm, eye irritation, chronic cough, wheezing, chest tightness, nasal congestion, difficulty breathing, headache and fatigue have also been reported in poultry workers (Donham et al., 2000; Kirychuk et al., 2003). The emergence of symptoms and illnesses after workers are exposed to environmental contaminants suggest that these pulmonary dysfunctions are a consequence of inhaled toxicants in poultry production. Therefore, without adequate controls and protection, individuals involved in broiler chicken production are at risk for pulmonary disease.

Many studies have researched the individual health effects of aerosol contaminants, but few have reported the effects of combined exposures. Donham et al. (2002) reported synergistic effects between dust and ammonia exposures associated with decreases in pulmonary function among workers in poultry production. Specifically, poultry workers completed pulmonary function tests before and after each shift and the relationship of total dust and ammonia exposures were examined by correlation, logistic modeling, and synergy index calculations. Results of this study concluded that synergistic effects between ammonia and aerosolized dust concentrations explained up to 43-63% of the pulmonary function decline over the work shift (Donham et al., 2002). This warrants discussions about occupational exposure limits (OELs) regulated by the Occupational Safety and Health Administration (OSHA) and leads to the question of whether or not OELs are protective enough when poultry workers are exposed to multiple contaminants.

Occupational Exposure Limits and Recommendations

There are no industry specific recommendations or standards for the agricultural sector and the OSHA permissive exposure limit (PEL) is the only legally citable standard in the U.S.; however, many broiler chicken farms are not audited by OSHA due to the small size and/or family approach (OSHA can only cite businesses with more than eleven non-relative employees). The OSHA general industry PEL for particulates not otherwise regulated is an eight-hour time weighted average (TWA) of 15 mg/m^3 for total dust and 5 mg/m^3 for the respirable fraction. The American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) for inhalable dust is 10 mg/m^3, also a TWA. The TLV of a contaminant is the level to which it is believed a worker can be exposed day after day for a working lifetime without adverse health effects. (United States Department of Labor, 2012)

The general industry OSHA PEL for ammonia is 50 ppm TWA. However, both the ACGIH TLV and National Institute of Occupational Safety and Health (NIOSH) recommended exposure limit (REL) are 25 ppm TWA and 35 ppm short-term exposure limit (STEL). A STEL is the average exposure over a 15 minute period of time. (United States Department of Labor, 2012)

There are no recommended exposure limits or standards provided by these agencies for endotoxin, pathogens or organic dust. Although recommendations can be found in the literature, these are not enforceable and are driven by research, as opposed to enforceable PELs. OELs should be focused on the inhalable and respirable concentrations of contaminants; total dust concentrations include particle size distributions that will not be inhaled by workers, and therefore will not contribute to the dose.

Previous dose-response research in the swine industry resulted in exposure limit recommendations. However, prior to 2000 no similar recommendations were reported for the poultry industry. Donham et al. (2000) assessed the pulmonary and respiratory function of broiler chicken production workers and identified thresholds at which adverse reactions occurred. Results suggested that concentrations should be well below 2.4 mg/m^3 total dust, 0.16 mg/m^3 respirable dust, 614 EU/m^3 endotoxin, and 12 ppm ammonia within poultry production confinements; these concentrations were associated with pulmonary dysfunction. (Donham et al., 2000)

Size Criterion and Sampling Strategies

The health effects of inhaled particles are dependent upon their toxicity and the region of the respiratory tract where they deposit (Verma, 1984). Inhalable particles enter the respiratory system though the nasal airway or mouth and can deposit within the respiratory tract. Large particles will either be exhaled or deposit in the upper lungs by sedimentation or impaction (Anna, 2011). Because human health effects are dependent on the size of the particle, industrial hygienists attempt to classify size distributions by using size specific sampling tools operated at the recommended flow rate.

Particles are classified by size as respirable, thoracic or inhalable (Anna, 2001). A variety of size dependent samplers can be used to measure dust concentrations; each with its own size specific criterion and measurable fraction. The cut-point diameter is the aerodynamic diameter of the particles collected at 50% efficiency. Respirable samplers have a cut-point at 4-µm (*i.e.*, Respirable Dust Aluminum Cyclone, SKC Inc., Eighty Four, PA), thoracic samplers have a cut-point at 10-µm and inhalable samplers collect particles that are between 50 and 100 μm at 50% efficiency. Inhalable samplers, including the Institute of Occupational Medicine (IOM) Inhalable Dust Sampler (Cat. No. 225-70A, SKC Inc., Eighty Four, PA) and the Button Aerosol Sampler (Cat. No. 225-360, SKC Inc., Eighty Four, PA), are often used to estimate personal inhalable dust exposure. The Button samples more precisely than the IOM during fast-air conditions and its curved cap is designed to minimize airflow turbulence and decrease the effects of both sampler position and wind velocity (Aizenberg et al., 2000). Although the Button sampler's cap can become blocked with debris, precise measurements can be obtained from this sampler and the curved-surface inlet is designed to improve the collection characteristics of inhalable dust and is ideal for both personal and area sampling (Aizenberg et al., 2000, Reynolds et al., 2009).

Exposure Control Strategies in Poultry Production

The industrial hygiene hierarchy of controls provides a framework for exposure control strategies. Exposure control strategies are used in a tiered approach of effectiveness, with the most effective strategies of exposure control being hazard elimination or substitution. Although these are among the most effective, they may not be feasible in the context of dust and ammonia control in the poultry industry. Specifically, poultry dust generation cannot be eliminated and ammonia is not a raw material used in production that can be substituted for another less hazardous material. Additional approaches used in the industrial hygiene hierarchy of controls include using an engineering approach to reduce concentrations of the hazard, or administrative controls to reduce personal exposure to the hazard. The last and least effective approach to reduce exposure to hazards is the use of personal protective equipment (*e.g.*, filtering face-piece respirator). Currently, the primary inhalation exposure control in poultry production is the use of respiratory protection.

Personal Protective Equipment

Personal protective equipment is recommended for broiler chicken production workers. However, limited information exists about respirator use among agricultural workers, specifically those involved in broiler chicken production. NIOSH and the Bureau of Labor Statistics (BLS) conducted a survey among U.S. employers regarding the use of respirators (Bureau of Labor Statistics, 2002). Results from this job-related survey indicated that 1,000 farms reported using respirators; however, 40% of these farms indicated that respirator use was voluntary and not required (Bureau of Labor Statistics, 2002). Across agricultural sectors, air sampling is typically not used to guide respiratory selection and the majority of workers and respiratory protection program administrators have no formal training. Furthermore, workers involved in broiler chicken production may not receive adequate training on respirator use. It is important to create a safety conscious environment within this industry to ensure workers understand hazards and properly use respirators, this is essential to decrease pulmonary disease among workers.

Within the agricultural sector, the prevalence of respirator use is low. For example, in 2006, from an estimated 2.1 million farm operators contacted, only 37.2% admitted to using a respirator on their farm; of those operators who used a respirator, 69.9% donned protective equipment while working in a dusty environment (Syamlal et al., 2013). This study indicated that additional research is needed to identify specific tasks for which respirators or dust masks are used, barriers to respiratory or dust mask use for other tasks, motivators for wearing respirators, and opportunities to increase the use of respiratory protection among farm operators, particularly on farms with fewer employees.

One study assessed the respiratory health, knowledge, and perception of wearing respiratory protection among a sample of poultry workers attending a regional farm show. The majority of workers ranked using respiratory protection as very important (51.9%); however, self-reported use of protective equipment was low (16.7%)(Kearney et al., 2014). Furthermore, associations between the importance of wearing respiratory protection and the number of poultry houses ($p = 0.04$), as well as using a respirator and the number of poultry houses ($p = 0.01$) were statistically significant (Kearney et al., 2014). Studies show that improved educational opportunities, including fit-testing and proper respiratory selection, should be emphasized for workers at smaller poultry farm operations and permanent control methods such as engineering controls should be used.

Administrative

A simple technique to reduce dust emissions from poultry buildings is regular house cleaning, including vacuuming and power washing between flocks, thereby reducing the volume and potential for contamination of the air in the house as well as air exhausted from the building (Donham, 2000; Mitchell et al., 2000; Jacobsen et al., 2001). The main steps for house cleaning include: removing equipment, litter or manure, dry clean, wet wash, disinfect, and thoroughly clean and disinfect the feeding and drinker systems (Patterson et al., 1997). Regular sweeping and vacuuming of poultry houses in locations where dust, feathers, and dander collect would likely improve air quality for birds and farm workers as well (Patterson and Adrizal, 2005).

Additionally, administrative techniques to reduce exposures can also include task and behavior modification. Nonnenmann et al. (2014) explored task modification approaches to decrease inhalation exposure to dust during broiler chicken worker's daily tasks. In this study, inhalable dust was measured while workers completed a daily task ("mortality pick-up") using both the traditional method and an experimental modified approach. The inhalable dust concentrations were lower when using the modified approach compared to the traditional method, 11.95 mg/m^3 and 16.24 mg/m^3, respectively (Nonnenmann et al., 2014). Simple solutions such as task modification may prove to reduce exposure in broiler chicken production workers, however, engineering controls could prove to be just as cost effective and are more protective for the workers.

Engineering Controls

Poultry Housing Systems

Studies continue to report differences in concentrations between poultry housing systems, documenting greater dust levels among floor-reared broilers compared with perch or cage layer systems (Wathes et al., 1997). These observations indicate beneficial properties of cage layer systems in terms of air quality for both poultry welfare and farmer health compared with popular perch-type systems or traditional floor-reared broilers (Patterson, 2005). Other nontraditional cage systems for broilers with manure belts that run intermittently removing manure from the house demonstrated potential benefits, including better air conditions, low levels of breast blisters, and bacterial contamination of skin and feathers (Patterson, 2005).

Higher concentrations of ammonia are also found in floor-reared broiler houses compared to cage or perch systems for layers; Wathes et al. (1997) reported differences in environmental ammonia concentrations between poultry housing systems in the UK with average concentrations in floor housed operations at 24.2 ppm and perch systems at 12.3 ppm. Similarly, ammonia emissions from housing systems for laying hens with litter were about 4 times higher than with cage operations without litter (Groot Koerkamp, 1994). Groot Koerkamp (1994) focused work on ammonia emissions and the relation to building design; scientific literature revealed that poultry systems with manure belts underneath cages reduced the emission rate of ammonia ten-fold when compared to deep pit housing systems. The efficiency of managing manure and emissions using a net-belted floor for broilers to eliminate the manure from the house was also demonstrated by Okumura and Hosoya (2000). These observations indicate beneficial properties of belted-cage or perch systems for layers and non-litter systems for broilers in terms of air quality for both poultry welfare and farmer health compared with traditional floor-rearing facilities. However, many growers must follow the production requirements of the company they are contracted with and new housing systems may not be economically feasible.

Litter Amendments

An important tool in modern broiler management is the use of litter amendments that can trap and hold litter nitrogen using one of several techniques, including adsorption, acidification, or salts to manipulate microbial populations and enzyme activities (Patterson and Adrizal, 2005). Reece et al. (1979), Terzich (1996), and Moore et al. (1996) demonstrated the ability of several compounds, including sodium bisulfate, ferric chloride, ferrous sulfate, phosphoric acid, superphosphate, and aluminum sulfate to reduce ammonia volatilization from the litter of floor-housed broiler operations. Work by

Kim and Patterson (2003) demonstrated that the addition of these chemicals can reduce microbial uric acid activity. Furthermore, Wilson (2000) reported on the application of liquid chemical litter amendment; ammonia concentrations at bird height were reduced from 70 to 40 ppm within 20 minutes of the first application, and with additional time ammonia concentrations continued to decrease to approximately 20 ppm within 3 hours.

Filtration

Filtration systems have been applied in field studies to assess dust reduction in swine production. Anthony et al. (2015) evaluated the performance of a recirculating ventilation system with dust filtration, and determined its effectiveness in improving air quality within swine farrowing rooms. Within this system, air was exhausted from the room, treated with a Shaker-Dust Collector, and returned to the farrowing room. Respirable and inhalable dust concentrations within the production room were reduced when using the filtration system by 41% and 33%, respectively (Anthony et al., 2015). This system successfully reduced dust concentrations in a swine farrowing room without increasing concentrations of hazardous gases. Future research is needed to identify if the use of a recirculating ventilation system with dust filtration would reduce dust and/or gas concentrations within poultry production.

Electrostatic Charging

Electrostatic charging of air in confined spaces has been used to reduce dust concentrations in both swine and poultry facilities (Mitchell et al., 2000; Czarick et al., 1985; Veenhuizen and Bundy, 1990). These devices impart a negative charge to airborne particles, resulting in their precipitation on grounded surfaces. Application of an electrostatic space charge system in a broiler breeder house resulted in a 60% reduction in airborne dust, total bacteria were reduced 76% and ammonia by 56% (Mitchell et al., 2003). Other studies within hatching and caged layer chicken operations using electrostatic particle charging have shown a dust reduction in particle sizes ranging from 0.3 to 25 µm (Mitchell et al., 2000; Gast et al., 1999). Although technically feasible, these scientists have cautioned that research understanding the economic advantages of electrostatic charging in commercial poultry houses still needs to be determined.

Sprinkling Systems

Coating surfaces with vegetable oil within animal confinements has been used in swine, cattle and poultry production. Sprinkling oil in swine barns has been successfully used to reduce dust (Nonnenmann et al., 2004) and other gases, including ammonia (Patterson and Adrizal, 2005). When using oil, it is important that droplet size is not too large, resulting in poor oil distribution, or too small, which may be a health hazard (Patterson and Adrizal 2005). According to Takai et al., (1998) droplet size should be greater than 150 µm to obtain effective liquid application. In housing for laying hens, an ultrasonic sprayer generating particles with a 2% solution of emulsified canola oil significantly reduced dust by nearly 50% (Ikeguchi, 2002). The authors also measured the settled dust on surfaces and found significantly greater amounts of settled dust in the sprayed house compared with the control house (Ikeguchi, 2002). Very high concentrations of dust at particle size diameters of 0.3 to 5.0 µm were also measured in control and oil-sprayed operations in floor-housed broilers; the sprayed house concentrations represented a significant 47% reduction in dust concentration (Ikeguchi, 2002). Von Wachenfelt (1999) compared dust concentrations in caged poultry systems before and during spraying periods; after spraying with an oil and water mixture, concentrations were reduced by approximately 50%.

Ellen et al. (2000) measured the impact of modifying relative humidity (RH) on dust concentrations in broiler chicken houses. In houses fitted with fogging equipment, inhalable dust concentrations were reduced by 13% in the fall and 22.5% in the spring, when the buildings were maintained at 75% RH, compared with control buildings. Ellen et al., (2000) observed a 50% and 65% reduction of the inhalable dust concentration after spraying water with 10% oil and pure water, respectively. Furthermore, immediate effects on respirable dust were observed after fogging with pure water and a water/rapeseed oil mixture. However, the researchers recommended that improved techniques for application of droplets onto dust sources would warrant higher dust reduction efficiency. (Ellen et al., 2000)

Water sprinkler cooling systems have been developed for use in broiler chicken production to reduce thermal stress (Grieve, 2003). Manufacturers promote these systems by advertising the system's inexpensive ability to: create activity which migrate the birds to feed and water, drastically reduce heat stress mortalities, and produce heavier birds at shipping, while being easy to maintain (Weeden Environments). Although the sprinkling systems are traditionally used to reduce thermal stress in livestock (Terrell and Marks, 2003), several investigations have shown that fogging, spraying, or sprinkling oil and/or water mixtures may also reduce hazardous concentrations of aerosolized dust (Takai et al., 1993; Zhang et al., 1995; Zhang et al., 1996; Zhang 1999; Jacobson et al., 1999; Lemay et al., 1999; Nonnenmann et al., 1999). However, currently these water sprinkling cooling systems have not been compared to other modes of cooling in a paired treatment and control experiment. Further research is needed to identify if water sprinkling systems work synergistically to cool the birds and decrease dust concentrations, thereby reducing worker inhalation exposure.

Statement of Problem and Objectives

Aerosolized contaminants generated by poultry production are numerous and can include dust, odors, endotoxins, microorganisms, and numerous gases including ammonia (Wathes et al., 1997; Takai et al., 1998; Seedorf and Hartung, 2000). These emissions in and around poultry production facilities can negatively impact both the bird and worker's health and respiratory performance. Management techniques to control, contain, or eliminate these air contaminants are numerous but vary in their cost, effectiveness, and practicality. Techniques for dust control include simple house cleaning, oil and water fogging, precipitation, use of certain housing systems and addition of equipment. Litter and manure amendments aid in reducing ammonia volatilization; many of the same control techniques to reduce dust will also reduce ammonia as well.

Agricultural workers are an underserved population with high rates of occupational illnesses, fatalities and limited resources for prevention (Lee et al., 2010; Hansen et al., 2002). Over 300,000 workers are directly involved with producing broiler chickens in environments containing harmful inhalable contaminants (National Chicken Council, 2012; Donham et al., 1990; Ellen et al., 2000). Pulmonary dysfunction among agricultural workers has been recognized for many years; however, changing systems within poultry operations are not monetarily advantageous for growers (Linaker and

Smedley, 2002). Furthermore, engineering controls are not frequently used and workers must rely on respirator use as their primary mode of protection.

Water sprinkling systems are used in broiler chicken production for thermal stress management and dust reduction. However, no data are available to evaluate if these commercially installed sprinkling systems reduce dust and ammonia concentrations. Therefore, the objective of this study was to evaluate the effectiveness of a commercially installed water sprinkler system to reduce inhalable dust and ammonia concentrations in a broiler chicken house. Because these water sprinkling systems are also used for thermal stress management of the broiler chickens, the results could demonstrate additional value for these systems. Growers may consider adding these systems to their productions buildings for contaminant reduction in addition to thermal stress management.

CHAPTER II

EVALUATION OF A SPRINKLER COOLING SYSTEM ON INHALABLE DUST AND AMMONIA CONCENTRATIONS IN BROILER CHICKEN PRODUCTION

Introduction

Indoor air contaminants such as dust and gases are present in concentrations that may be hazardous to worker health in poultry production. Workers are exposed to inorganic and organic dust as well as ammonia, hydrogen sulfide and microorganisms during daily work activities (Rimac et al., 2010; Viegas et al., 2013). Organic dust in poultry production is composed of feed, feces, urine, feathers, bacteria and fungi (Nonnenmann et al., 2012; Viegas et al., 2013). Hazardous concentrations are due to inadequate ventilation and some evidence suggests that indoor air contaminant concentrations increase in the winter months. Also, as birds age, fecal and urine biomass concentrations increase during the growth cycle and feather debris increases with bird size (Lawniczek-Walczyk et al., 2013).

Workers in animal production have a higher prevalence of adverse respiratory symptoms than other farmers and rural residents (Kogevinas et al., 1999; Radon et al., 2001; Rimac et al., 2010). Inhalation of dust and/or gases in animal housing can lead to respiratory diseases (Mutel and Donham, 1983). Specifically, inhalation exposure to poultry dust has been associated with respiratory symptoms and lung diseases among agriculture workers, including broiler chicken production workers (Iversen et al., 2000; de Alencar et al., 2004). Poultry workers may also have sensitization allergic reactions to mold and/or dust mites which thrive in the poultry litter environment (Rimac et al., 2010).

Chickens raised specifically for meat production (broilers) are produced in floor-housed facilities that are large, open structures. The poultry production houses are designed to provide optimal conditions for broiler chickens to grow, including mechanical systems to deliver feed and water to the birds and environmental systems that provide ventilation and heat (National Chicken Council, 2012). Production time for broiler chickens, from chick placement to harvest, ranges from 28 to 63 days (MacDonald, 2008). During this growth period, workers are responsible for tracking growth, maintaining environmental conditions in the house, removing deceased birds, and performing equipment maintenance (Cobb, 2008). Upon harvest, the birds are removed and the poultry house litter may be tilled to redistribute and/or de-cake the litter. The poultry litter in the house consists of organic matter such as wood chips, rice hulls, or peanut shells (National Chicken Council, 2012). Air within the poultry house is mechanically exhausted to the outdoors to minimize thermal stress and contaminant concentrations that may be harmful to the flock.

Kirychuk et al. (2006) determined that total dust and ammonia exposures were significantly greater among workers in floor housed poultry buildings, compared to cage-housed operations. Furthermore, a range of inhalable dust concentrations have been reported in the scientific literature, all of which are above the recommended occupational exposure limit (OEL) of 2.7 mg/m^3 for inhalable dust (Donham et al., 2000). Specifically, geometric mean inhalable dust concentrations for floor-housed operations in the U.S. were 24 mg/m^3 (Lenhart et al., 1990), 8 to 9 mg/m^3 in Europe (Ellen et al., 2000), and 21 mg/m^3 in Iran (Golbabaei et al., 2000). In the UK, respirable and inhalable dust concentrations are also significantly higher in floor-housed broiler operations compared to cage operations (Wathes et al., 1997). Little task specific exposure data is available; however, Louhelainen et al. (1986) concluded that workers involved in catching mature broilers at the end of the production cycle were exposed to inhalable dust concentrations at 37.6 mg/m^3. This information suggests that workers performing tasks in floor-housed poultry operations may be at risk for exposure to inhalation hazards. Therefore, research is needed on engineering controls to reduce inhalation hazards (*e.g.*, inhalable dust) within floor-housed broiler chicken operations.

The current personal inhalation exposure control for dust and ammonia among agricultural workers is the use of respiratory protection (*e.g.*, filtering face-piece respirator). NIOSH and the BLS conducted a survey among employers in the U.S. regarding the use of respirators. According to this survey, within the agricultural, forestry and fishing sectors approximately 5% of workers in these establishments used respirators. Results from this job-related survey specified that over 1,000 farms reported using respirators; however, over 40% of farms indicated that respirator use was voluntary and not required. Little evidence is available that indicates that air sampling is performed to guide the selection of respiratory protection equipment. Also, the majority of workers and respiratory protection program administrators have no formal training in using and selecting respirators. No information exists concerning respirator use among workers involved in broiler chicken production; furthermore, these workers may not receive adequate training on respirator use. Using the industrial hygiene paradigm, engineering controls are prioritized above other control methods. Therefore, an engineering control method is needed to control concentrations of dust and gases in poultry production. (Bureau of Labor Statistics, 2002)

Few engineering controls have been evaluated to reduce dust concentrations in animal production. Coating surfaces with vegetable oil has been used to control dust in swine, cattle and poultry production. Nonnenmann et al., (2004) demonstrated that oil treatments successfully reduce dust concentrations in swine production. However, there were limitations to these trials. Oil sprinkling resulted in worker safety (*e.g.*, slippery conditions in work areas) and production issues (*e.g.*, mite infestation on poultry)(Zhang et al., 1996). Furthermore, using oil sprinkling did not reduce exposure concentrations below the industry specific limit recommended by Donham et al. (2000). Also, ammonia concentrations were not reduced in these oil-sprinkling studies.

Water sprinkler cooling systems have been developed for use in broiler production (Grieve, 2003). These sprinkling systems are used to reduce thermal stress in livestock (Terrell and Marks, 2003). Several investigations have also shown that fogging, spraying, or sprinkling oil and/or water mixtures may also reduce hazardous concentrations of aerosolized dust (Takai et al., 1993; Zhang et al., 1995; Zhang et al., 1996; Zhang 1999; Jacobson et al., 1999; Lemay et al., 1999; Nonnenmann et al., 1999). Additionally, these water sprinkling cooling systems use a fraction of the water needed to operate other cooling systems (*i.e.*, cooling pads or cells) (Tabler et al., 2009). These sprinkler cooling systems are advertised to effectively create activity that moves the birds to feed and water, reduce heat stress mortality, and reduce dust in houses (Weeden Environments). However, peer reviewed data from studies that used pure water sprinkling systems are limited to substantiate this claim. Although previous studies have not investigated the use of sprinkling systems to reduce ammonia concentrations, houses with these systems can typically be maintained at warmer temperatures than houses using other modes of cooling. If managed properly, the litter moisture in sprinkler houses remains lower and therefore potentially have lower concentrations of aerosolized ammonia. Water sprinkling systems may work synergistically to cool the birds and decrease dust and ammonia concentrations, thereby reducing worker inhalation exposure.

Approximately 40 companies in the U.S. are involved in the business of raising, processing and marketing broiler chickens; these companies directly and indirectly employ approximately 500,000 workers including those working at over 30,000 family farms across the country (National Chicken Council, 2012). Global broiler chicken production has exceeded 80 million pounds each year since 2001 (The Poultry Site, 2014); the U.S. is the largest producer of poultry meat in the world. Also, poultry production is the largest meat producing industry in the U.S., The National Chicken Council projected that 40 billion pounds of poultry meat were produced in the U.S. in 2015 (National Chicken Council, 2012). The broiler chicken industry is based on standard industry guidelines that all growers are contracted to uphold. Therefore, introducing engineering controls to reduce inhalation hazards has the potential to significantly impact worker health if the control method is required as part of the grower's contractual agreement with the poultry company.

The objective of this study was to evaluate the effectiveness of a water sprinkling system to reduce inhalable dust and ammonia concentrations in a broiler chicken house. Within this study, concentrations of inhalable dust and ammonia within a treatment broiler chicken house were compared to concentrations in a control house.

Methods

Experimental Conditions

This study was conducted during the winter of 2015 (January to March) in two broiler production houses located at Mississippi State University (Mississippi State, MS). The buildings were approximately 129 m long, 13 m wide and floor-housed approximately 20,000 chickens for the duration of a broiler growth period (63 days). Both buildings had curtain sided walls; each were equipped with mechanical ventilation and infrared heaters to maintain temperature and relative humidity levels (based on the growth stage of the chickens). The buildings were equipped for transitional ventilation, including ten 48-in (1.3 m) fans and tunnel doors for tunnel ventilation and 62 side air inlets along the length of the house for minimum ventilation; the ventilation systems for both buildings were operated alike during the sampling period. Cooling pads were located opposite the fans and 20 infrared heaters (40,000 BTU) were located throughout the house. The litter inside each house was treated with an ammonia amendment (liquid alum and sulfuric acid) prior to the trial.

Sprinkling System

The poultry houses were equipped with commercially installed water-based sprinkler cooling systems (The Weeden Sprinkler System®, Weeden Environments Inc., Woodstock, ON). Traditionally, this sprinkling system is used as a cooling device in poultry production. This low maintenance system consists of the manifold which is installed in the front entrance of the barn and the sprinkler drops which are typically 40 cm long and are placed within ¾ in (1.91 cm) diameter polyvinyl chloride (PVC) water line attached to the ceiling down the length of the barn. Both houses were equipped with this system; however, only one was activated for the duration of this trial (treatment versus control). The sprinkler system consisted of two rows of twenty sprinkler heads, each were 6 m apart. The sprinkler activation occurred between 6 am and 10 pm and the schedule was as follows: days 1-4 none, days 5-9 5 five s/h, days 10-14 ten s/h, days 15-harvest fifteen s/h; this schedule followed the manufacturer's recommendation for dust control and bird activity promotion. During 20 s of water sprinkling, each sprinkler emits 237 ml of water over an area of 47 m^2, totaling 18 l of water dispersed throughout the entire house for each sprinkler activation. A diagram of the houses, including the locations of the fans and sprinkling heads is shown in Figure 1.

Sampling

Inhalable dust concentrations were measured with a Button Aerosol Sampler (Catalog Number 225-360, SKC Inc., Eighty Four, PA). Polyvinylchloride filters were used (25-mm, 5 µm pore size; Product Number 225-5-25, SKC Inc., Eighty Four, PA) for sampling and were analyzed gravimetrically and blank corrected. Pre/post flow rate calibration was performed using a field rotameter (Dwyer VFA Series Flow Meter, Dwyer Instruments, Michigan City, IN) calibrated to a primary standard (Defender 510, Mesa Labs, Inc., Butler, NJ). All air sampling was performed using a personal sampling pump (Airchek XR5000, SKC Inc., Eighty Four, PA) operating at 4 lpm. Dust samples were collected for 30 minutes each day in each poultry house for an entire production cycle (approximately 63 days); sampling occurred approximately 3 h after sprinkler activation began each day. The sampler was attached to a stationary mannequin near the breathing zone (1.5 m from the floor). The mannequin was centrally located between the side-walls, 30.5 m upstream from the exhaust fans, throughout the duration of the experiment. Samples collected during this period were stored in a -20°C freezer before being transported to the laboratory for gravimetric analysis. The filters were placed in a desiccator (RH = 20-30%; temperature = 25 ± 2˚C) for at least 24 hours prior to measurement, and were weighed using a 6-place microbalance (Mettler Toledo Microbalance XP26, Mettler-Toledo International Inc., Greifensee, Switzerland) to the nearest µg. Gravimetric dust concentrations were computed from filter weight gain (blank corrected) and total sampling volume. Inhalable dust concentrations were reported in mg/m^3. Environmental conditions in both houses were monitored by a direct reading instrument (Enviro-Meter, VWR International, Radnor, PA) to compare across treatment and control buildings (Table 1).

Ammonia gas concentrations were measured using a direct reading sensor (ToxiRAE Pro, Rae Systems, San Jose, CA) located in the breathing zone of the mannequin. Samples were collected in each poultry house for 15 min to correlate with the instrument's short term average logging feature; sampling for dust and ammonia occurred at the same time. The ammonia concentrations were reported in ppm; the sensor had a resolution of 1ppm. The ammonia sensor logged results every 10 seconds; the device was calibrated throughout the sampling period using 50 ppm calibration gas (Product: NLBF100550PN, Midwest Safety Counselors, Inc., South St. Paul, MN)

An optical particle counter (OPC) (model 1.108, GRIMM Technologies, Inc., Douglasvillle, GA) was used to measure the aerosol inside the treatment and control houses. The OPC measured particle number concentration by size from 0.3 to 25-µm, separating the concentrations into fifteen bin channels. A stainless steel tube (4-mm outer diameter by 3-mm inner diameter) provided by the manufacturer was used as the inlet.

Sampling was conducted in the morning and afternoon for 30 minutes within each house; the instrument operated at 1.2 lpm and was set to report a size distribution every six-seconds. The instrument was calibrated by the manufacturer prior to starting this experiment. Sampling took place prior to water sprinkling activation to ensure similar particle size distributions within each house. The instrument reported particle number concentrations in #/l for each size bin. A summary of the air sampling monitoring equipment, calibration and contaminant measured is described in Table 2.

Data Analysis

Inhalable dust and ammonia measurements collected after sprinkler activation began (Day 5) were analyzed. The Shapiro-Wilk normality test was conducted to determine the sample's distribution; data were log-transformed if found to be log-normally distributed. If data were neither log-normally distributed nor normally distributed the data were log-transformed if the distribution became more linear when plotted using log-probability scales. Descriptive statistics were conducted and a two-sample t-test was used to determine statistically significant differences in geometric mean dust and ammonia concentrations measured in poultry houses operating with differing conditions (treatment and control). A chi-square analysis was initially conducted to determine whether the sample variances were significantly different. Measurements greater than three standard deviations from the mean were identified as outliers and removed from the analysis. Data collected with the OPC were used to calculate the count median diameter (CMD) and geometric standard deviation (GSD) of particles measured during each sampling period; these results were calculated using the weighted mean method for determining CMD (Hinds, 1999). Data were analyzed using Microsoft Excel, SAS 9.3 (Cary, NC, USA) and Minitab 17 (State College, PA, USA); a p-value < 0.05 was used as the criteria for statistical significance.

Results

Inhalable Dust

Fifty-five area dust samples were collected in each house (Figure 3). The inhalable dust concentrations in the treatment house (sprinkler activation) were log-normally distributed ($p = 0.10$); however, the inhalable dust concentrations in the control house (no sprinkler activation) were neither normal ($p = 0.0002$) nor log-normally distributed ($p = 0.02$). The geometric mean dust concentration in the treatment house was 5.52 mg/m^3 (GSD: 1.59) and the geometric mean dust concentration in the control house was 6.00 mg/m^3 (GSD: 1.75).

Statistical analyses were completed on the log-transformed data to determine if there were significant differences in geometric mean inhalable dust concentrations measured in poultry houses operating under the two conditions. Although inhalable dust concentrations measured in the treatment house had less variability (the range from highest to lowest concentration was lower in the treatment house) and geometric mean concentrations were 11% lower in the treatment house, the difference between the two houses was not statistically significant ($p = 0.33$; Figure 4).

The OPC was used to evaluate whether the particle size distributions were similar across the treatment and control houses. Prior to water sprinkling activation, the CMD and GSD of dust particles measured in each house (morning and afternoon) were similar; these results are highlighted in Table 3.

Ammonia Gas

Fifty-five area measurements of ammonia were also collected in each house. The distribution of the ammonia concentrations within the treatment and control houses did not pass a normality test (normal: $p \leq 0.05$, log-normal: $p \leq 0.05$). Log-normalizing the data did make the distribution more linear when plotted; therefore, the ammonia data were log-transformed. The geometric mean ammonia concentration within the treatment house was 10.6 ppm (GSD: 1.80); the geometric mean concentration within the control house was 9.51 ppm (GSD: 1.77). The difference in geometric mean concentrations between the houses were not significantly different ($p = 0.35$; Figure 5).

Discussion

Geometric mean inhalable dust concentrations collected in the treatment house (5.52 mg/m^3) were lower than those found in the control house (6.00 mg/m^3); however, the difference was not statistically significant. These concentrations were similar to those found in a previous study by Ellen et al. (2000). Although the sampling time was much shorter in this study, the concentrations were consistent with those found in broiler production houses in Canada as well; Just et al. (2009) measured inhalable dust concentrations ranging from 0.02 to 81.33 mg/m^3.

Although the differences in concentrations of inhalable dust and ammonia were not statistically significant, the variation of concentrations measured were reduced. This difference cannot be attributed to differing environmental conditions or particle concentrations. Measurements obtained using the OPC verified that particle size distributions were similar within both houses prior to sprinkler activation. Therefore, the differences in concentrations measured and the reduced variation were caused by factors within the houses during the experimental conditions. Furthermore, dust concentrations did not increase as the birds aged and become larger in size (Figure 3). Inhalable dust concentrations remained relatively constant during the sampling period, contrary to what previous research has shown. Lawniczek-Walczyk (2013) found that contaminant concentrations increase toward the end of the growth period as a result of increased fecal and urine biomass and feather debris as birds grow.

Even though inhalable dust concentrations were reduced (not statistically significant, $p = 0.33$) using the water-sprinkler as an engineering control for dust, the magnitude of inhalable dust and ammonia concentrations were still above recommended limits of 2.7 mg/m^3 and 12 ppm for inhalable dust (Figure 4) and ammonia (Figure 5), respectively for the poultry industry (Donham et al., 2000). Although some reduction in dust concentrations is beneficial, the magnitude of the reduction was neither enough to eliminate the need for use of respiratory protection equipment; nor reduced below the OELs referenced in Table 4. Adverse health effects have been observed with poultry dust concentrations of this magnitude and respiratory protection should be used to decrease exposures until controls are in place that mitigate the hazards (Donham et al., 2000).

Temporal, spatial and environmental factors were controlled for in this experiment. Sampling was completed in a location 30.5 m upstream from exhaust fans in the tunnel-ventilated houses; this location was stationary throughout the entirety of the experiment and sampling was completed at the same location in each house. Also, due to air movement throughout the house, this location likely has the highest contaminant concentrations and may be representative of the worst case scenario for workers.

Contaminant concentrations may have been influenced by seasonal weather. However, to control for weather variability, paired sampling was employed between the treatment and control buildings. Because sampling was conducted simultaneously in each house, error attributed to these factors would be non-differential.

Limitations

Sampling was conducted at one broiler chicken farm, this could impact the generalizability of the results. The sprinkler's activation settings may have also impacted the reduction of inhalable dust and ammonia; however, the manufacturer's recommendations for sprinkling duration and frequency were used in this study. A future experiment could focus on the comparison of inhalable dust and ammonia concentrations collected under a variety of sprinkling conditions (*i.e.*, variety of sprinkling schedules and amount of water delivered during each activation) paired with the introduction of a chemical litter amendment.

Conclusion

Geometric mean inhalable dust concentrations were reduced by over 10% in the treatment house utilizing a water sprinkling system that is designed to control thermal stress. However, the difference in geometric mean concentrations of inhalable dust and ammonia across the treatment and control house were not statistically significant. The observed reduction in dust and ammonia concentrations was not sufficient enough to eliminate the use of respiratory protection. However, the range in dust concentrations was lower in the treatment house and the highest concentration measured in this house was approximately 6 mg/m^3 less than that measured in the control house. Additionally, this difference was not attributed to dissimilar baseline particle concentrations; measurements verified that both houses had comparable dust particle number and size distributions prior to the activation of the water sprinkling system.

Future research should evaluate the effectiveness of adding a chemical amendment to the poultry house litter. Using a liquid litter amendment, in addition to the sprinkler system, may reduce re-aerosolization of dust in the poultry house due to the crust formed atop the litter bedding. Using a different sprinkler activation schedule may also be beneficial to determine if occurrence of sprinkling and amount of water released has an effect on dust and ammonia concentrations. More trials with sprinkling systems may prove to reduce ammonia concentrations. If managed correctly, houses with sprinkling systems can be maintained with higher temperatures and a lower relative humidity, compared to houses with cool cells. These factors contribute to moisture reduction within the poultry litter; consequently, less expression of ammonia gas is detected within the chicken house.

Additional research is needed to further understand inhalation exposure hazards and the use of multiple exposure control technologies synergistically. The use of cost effective engineering, administrative and personal exposure controls are needed in the poultry industry to effectively reduce worker's exposure to hazardous concentrations of dust and ammonia. Continuous collaboration between research institutions and industrial partners is essential to develop conclusive research that reduces exposures, controls hazards and promotes worker health.

Table 1. Environmental conditions evaluated within broiler chicken houses.

Condition, units	**Control House Mean (SD)**	**Treatment House Mean (SD)**
Indoor Temperature, ˚C	19.6 (3.1)	19.2 (2.3)
Indoor Relative Humidity, %	59.5 (10.6)	61.8 (8.8)

Table 2. Summary of air quality monitoring equipment.

Contaminant, units	**Device**	**Operation**	**Calibration**
Inhalable Dust, mg m^{-3}	Button Aerosol Sampler- PVC filter with 5-µm pore	4 lpm, Airchek XR5000	Rotameter, SKC Multi-Purpose Calibration Chamber
Dust, direct-reading	Portable Aerosol Spectrometer 1.108 (GRIMM Technologies, Inc.)	1.2 lpm, 6-sec logging interval	Performed by Manufacturer
Ammonia, ppm	ToxiRAE Pro (Rae Systems, San Jose, CA)	10-sec logging interval	NH_3 = 50 ppm
Temperature, ˚C Relative Humidity, %	VWR Enviro-Meter (VWR International, Radnor, PA)	60-sec logging interval	Performed by Manufacturer

Table 3. CMD of dust particle distributions measured* using an OPC in poultry houses.

Poultry House	Time of Day	CMD (μm)	GSD
Control	Morning	0.755	2.52
	Afternoon	0.740	2.49
Treatment	Morning	0.711	2.44
	Afternoon	0.702	2.42

*Sampling took place prior to sprinkling activation, 30.5 m upstream from exhaust fans.

Table 4. Exposure thresholds for broiler chicken house contaminants.

Threshold*	Inhalable Dust, mg m^{-3}	NH_3, ppm
OEL	10	25
Industry Recommendation	2.7	12

*OEL based on 8-hr ACGIH TLVs; Industry recommendations from Donham et al. (2000)

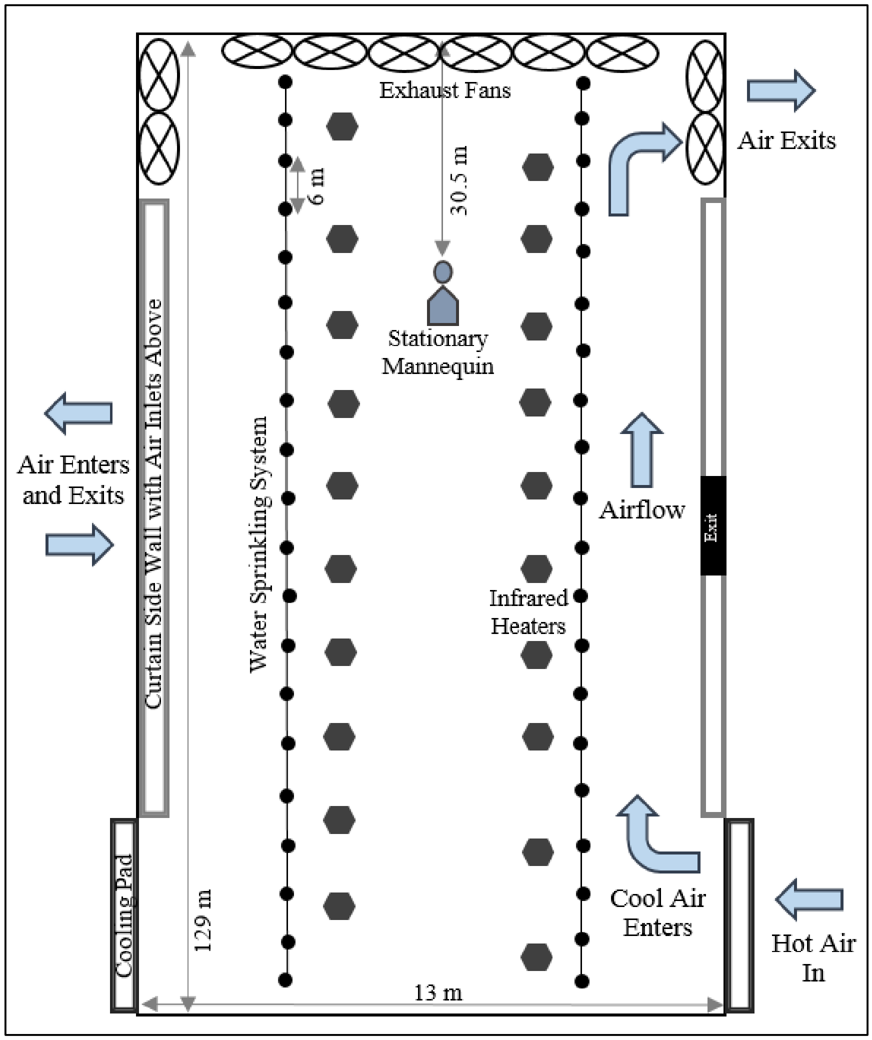


Figure 1. Aerial view schematic of broiler chicken production house.

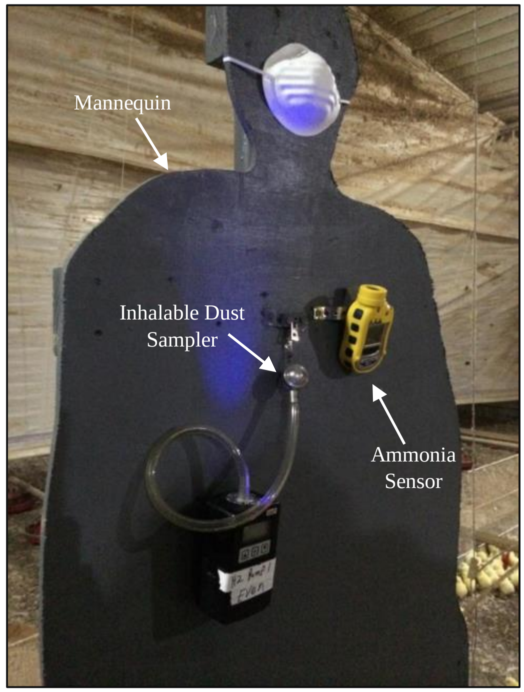


Figure 2. Sampling equipment on stationary mannequin.

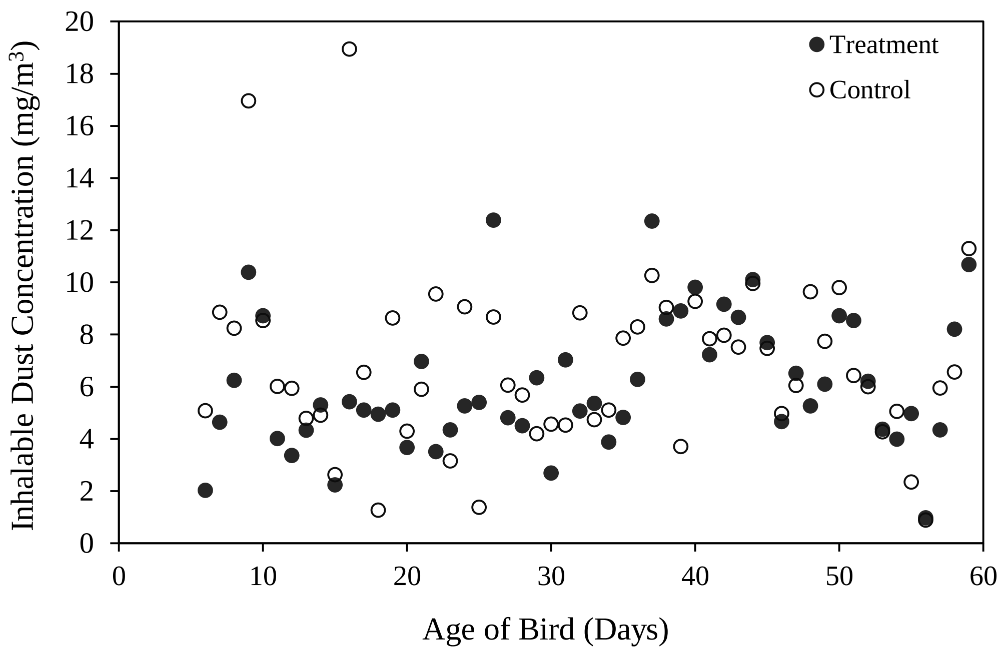


Figure 3. Inhalable dust concentrations in each broiler chicken house throughout the growth period.

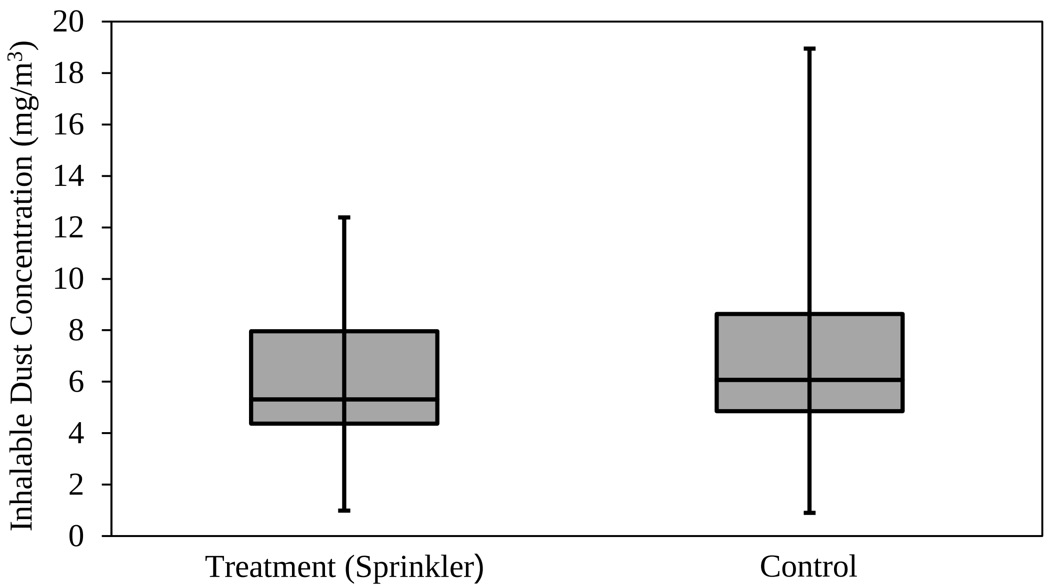


Figure 4. Comparison of inhalable dust concentrations in broiler chicken houses across the experimental conditions. The center horizontal line is the median concentration measured in the house; the error bars represent the highest and lowest concentrations measured (N=55 for both).

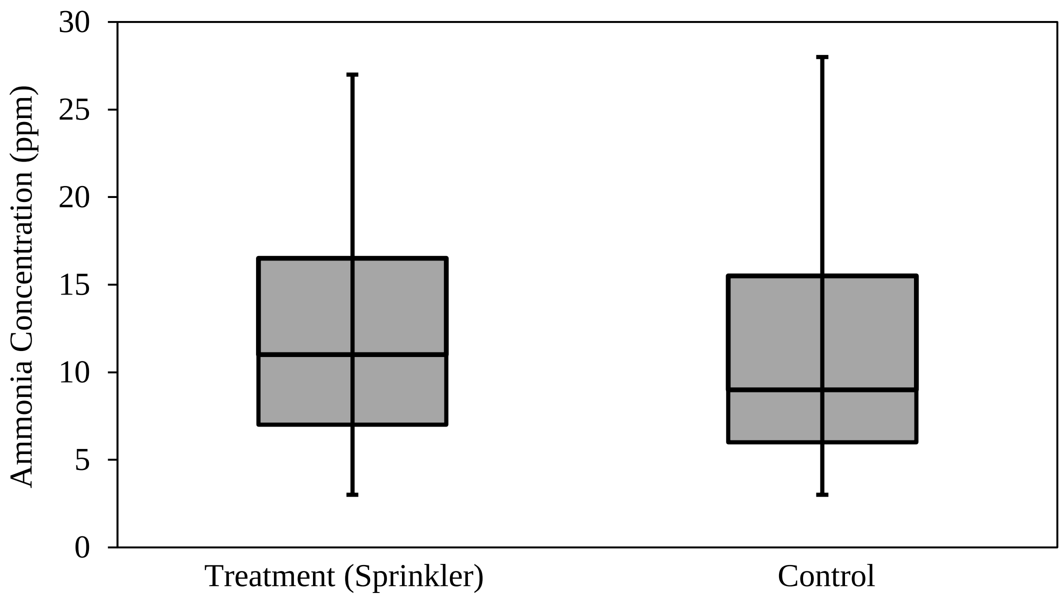


Figure 5. Comparison of ammonia concentrations in broiler chicken houses across the experimental conditions. The center horizontal line is the median concentration measured in the house; the error bars represent the highest and lowest concentrations measured (N=55).

CHAPTER III

CONCLUSION

Research that evaluates engineering control technology to reduce airborne concentrations of dust and ammonia in broiler chicken production is lacking. In this study, researchers evaluated the use of a water sprinkling cooling system to reduce inhalable dust and ammonia concentrations within broiler chicken production houses. Paired area sampling was conducted in a treatment house and a control house; the treatment house was equipped with an activated commercially installed water sprinkling system, this was the only difference between the two houses. This experimental design decreased sampling bias associated with environmental conditions, spatial and temporal factors and variances between flocks. Although the difference in mean dust and ammonia concentrations were not statistically significant, the mean inhalable dust concentration was reduced by over 10% in the treatment house (when compared to concentrations in the control house).

This study was conducted at one broiler chicken farm during one production cycle, employing this experiment in more farms may make the results more generalizable. Also, it may be beneficial to conduct the study over a longer period of time that includes multiple production cycles; this would increase the sample size of the experiment. In this study the manufacturer’s sprinkling activation schedule to control for dust and bird activity was implemented. A future study could be conducted pairing a filtration system and a sprinkling activation schedule that deploys more water per sprinkling event or the addition of more water sprinkling events per day. These sprinkling sessions could also be activated when workers are completing high exposure tasks.

However, during times of increased sprinkling it is necessary to continuously monitor mold and ammonia, which thrive in moist litter environments.

In this study, a liquid litter amendment (liquid alum and sulfuric acid) was distributed across the litter prior to chick arrival and initiation of the water sprinkling. The use of a water sprinkling system paired with other chemical litter amendments may prove to decrease re-aerosolization of dust and reduce concentrations. Although the focus would be to decrease dust and ammonia concentrations in the house it is very important to take into consideration the health of the chicken. Therefore, it is essential to continue a working relationship with poultry production scientists and integrator companies to test and implement viable and affordable exposure control technologies.

Additional research could focus on evaluating workers' personal exposures; personal exposure is more representative of risk than area concentrations. Furthermore, task specific personal air sampling could be conducted to identify behaviors and/or processes that put workers at risk of being overexposed. Lastly, contaminant mapping could be completed to investigate locations inside the broiler chicken houses that contain the highest concentrations. Limited research has identified the prevalence of respiratory protection use among broiler chicken production workers. Further studies and training implementation are needed to understand the worker's decisions and ensure these workers understand risky behaviors and tasks that require respirator use.

When providing broiler chicken growers with findings from research it is important to establish a trusting relationship and provide information that is beneficial to their operations. Water sprinkling cooling systems not only reduce concentrations of inhalable dust, but also require a fraction of the water needed to operate other cooling systems (*i.e.*, cooling cells). Furthermore, these sprinkling cooling systems promote bird activity and require relatively little maintenance. Because these water sprinkling cooling systems are both financially beneficial to the grower and potentially increase worker health and safety, it is important to continually share results with broiler chicken integrators. Although barriers are present when delivering these findings to the target area, the public could receive this information through extension and poultry publications, and word of mouth from farmer to farmer. It is essential to continue collaboration between research institutions and industrial partners, as well as industrial hygienists and poultry scientists to provide further research, break down communication barriers between the groups, and promote worker health and safety.

APPENDIX A: OPERATING PROCEDURES FOR SAMPLING EQUIPMENT

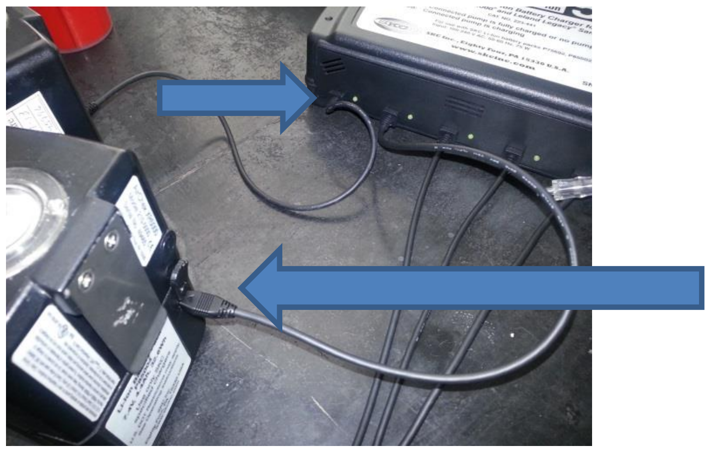
Field Sampling Protocol - Broiler Chicken Farm

Inhalable Dust: Using Button Aerosol Sampler

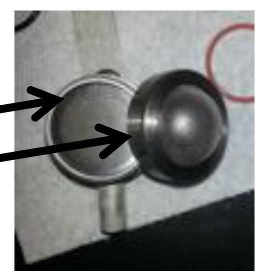
The goal of this protocol is to provide instructions on how to perform field area sampling for inhalable dust and ammonia. The sampling procedures will be described in detail below.

I. Charging pumps the night before sampling.

1. The night before sampling plug in the pump charger and attach the pump to one of the charging leads. The indicator light will turn green when the pump is full charged (see below).



II. Assembling the sampling equipment.



1. Unpack Button Aerosol sampler and parts
    a. Sampler Base
    b. Black Rubber "O" ring
    c. Perforated Metal Filter backup pad
    d. Red "O" ring
    e. Sampler Top
    f. Red Sampler Cover (Not pictured)
2. Remove filter from holder with tweezers and place in Sampler Base
3. Place Red "O" ring on top of filter

4. Snugly screw Sampler Top on to the Sampler Base

III. Pre-calibrating the airflow on the pumps through the samplers

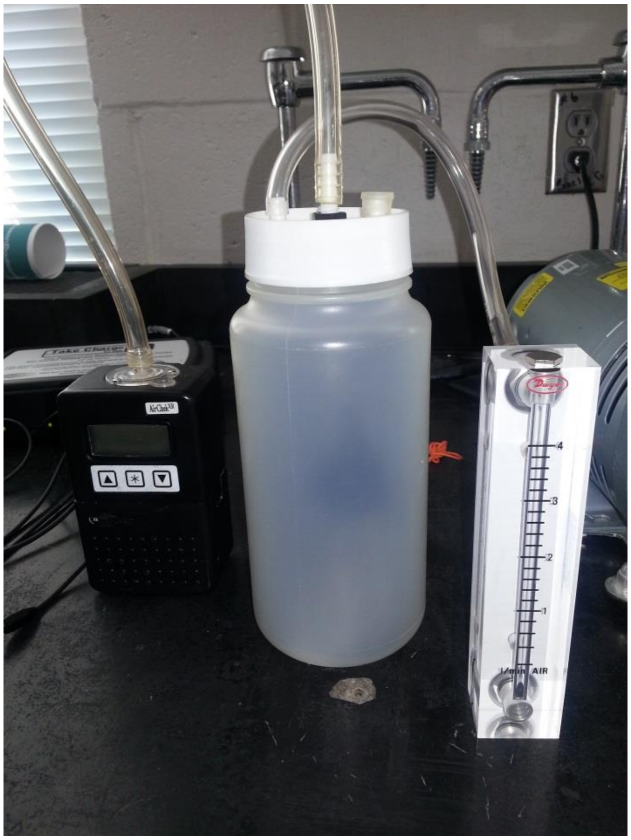
1. INHALABLE DUST SAMPLER

   1.1 Attach tubing to the "inhale" pump.

   1.2 Attach tubing from the "inhale" pump to top of the white lid.

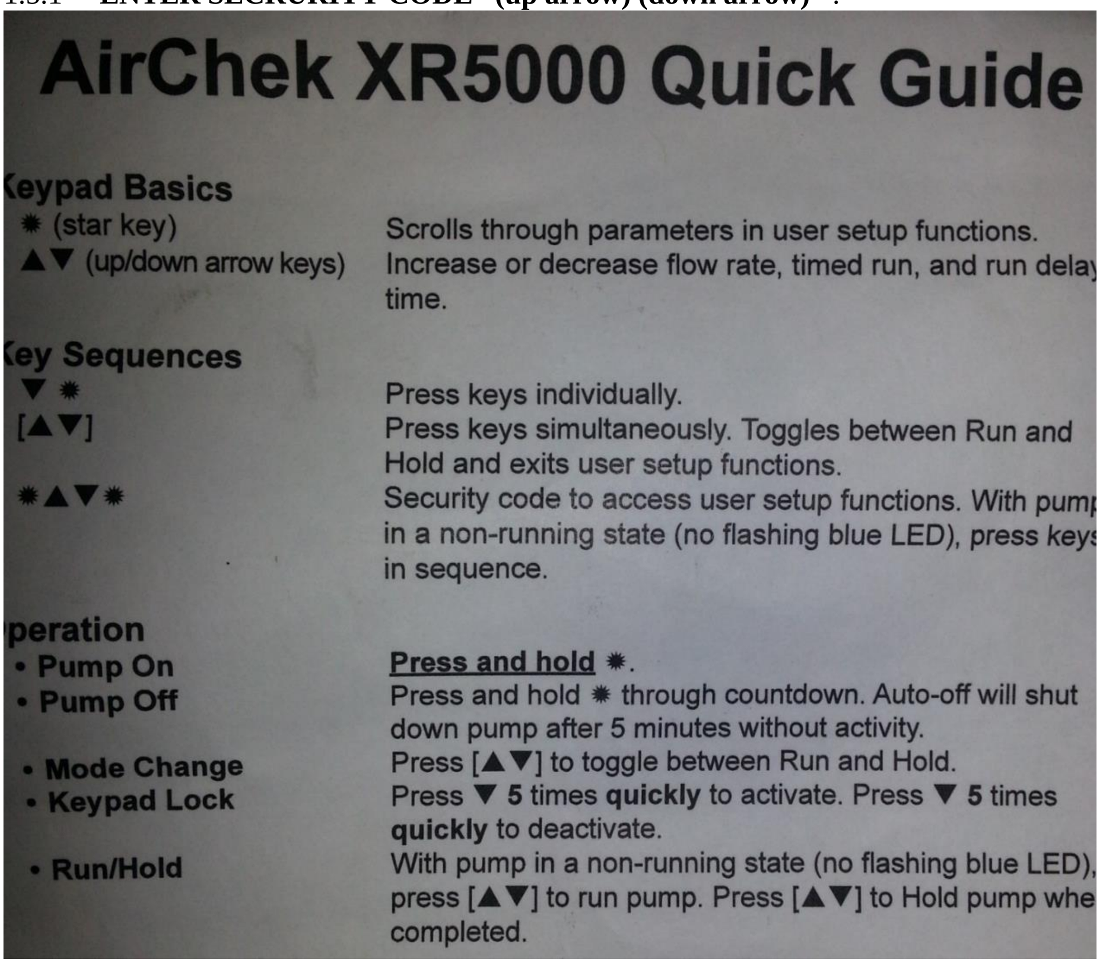
1.3 Attach Button sampler to tubing on the bottom of the white lid, gently place in jar, screw lid on tightly

1.4 Attach tubing from the top of the rotameter to the top of the white lid – to complete the setup below.



1.5 Activating the pump by simultaneously pushing on both arrow buttons.

1.5.1 **ENTER SECRURITY CODE *(up arrow) (down arrow) ***.



AirChek XR5000 Quick Guide

eypad Basics

✹ (star key)	Scrolls through parameters in user setup functions.
▲▼ (up/down arrow keys)	Increase or decrease flow rate, timed run, and run dela time.

ey Sequences

▼ ✹	Press keys individually.
[▲▼]	Press keys simultaneously. Toggles between Run and Hold and exits user setup functions.
✹▲▼✹	Security code to access user setup functions. With pump in a non-running state (no flashing blue LED), *press keys* in sequence.

peration

• **Pump On**	<u>**Press and hold**</u> ✹.
• **Pump Off**	Press and hold ✹ through countdown. Auto-off will shut down pump after 5 minutes without activity.
• **Mode Change**	Press [▲▼] to toggle between Run and Hold.
• **Keypad Lock**	Press ▼ **5** times **quickly** to activate. Press ▼ **5** times **quickly** to deactivate.
• **Run/Hold**	With pump in a non-running state (no flashing blue LED), press [▲▼] to run pump. Press [▲▼] to Hold pump whe completed.

1.5.2 Press * to navigate to the flashing screen display of "---".

1.5.3 Press the "up" arrow. The pumps should start and the "black ball" on the rotameter should be floating at **4.*0*** L/Min. If the ball is in another location, ***adjust the flow using the "up or down" arrows to make the flow* 4.0 *L/min.*** ***(THIS MUST BE CORRECT!).*** – see below

1.5.4 Pause the pump by simultaneously pushing on both arrow buttons. Dissemble the calibration set up and attach the BUTTON AEROSOL sampler to the pump. **MAKE SURE THE TUBING IS SEATED TIGHTLY AGAINST THE SAMPLER**

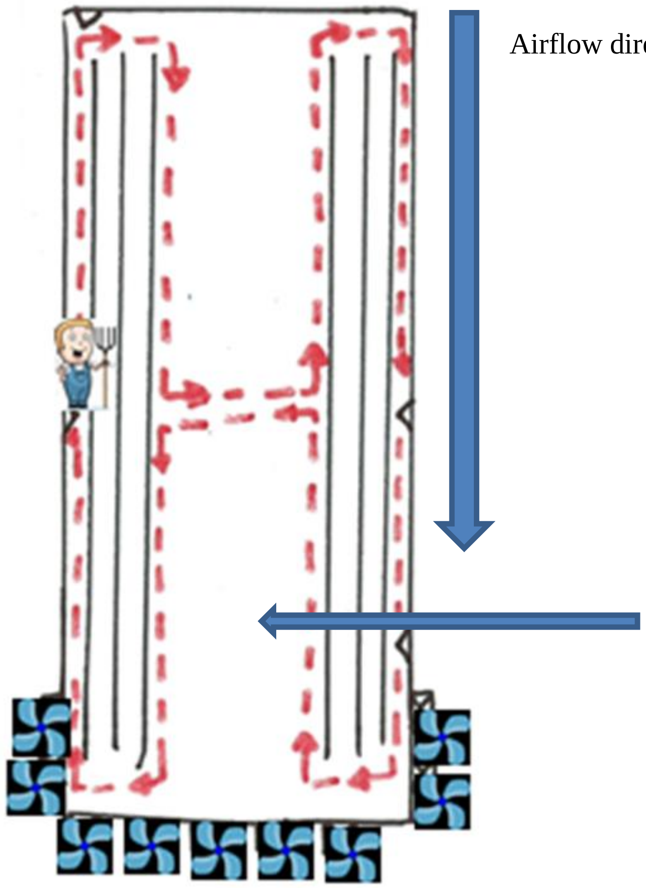
1.5.5 Activate the pump by simultaneously pushing on both arrow buttons when you are ready to sample.

IV. Sampling at the farm

1. Assemble samplers as described above.

2. Place sampling stand in correct location and attach samplers

   2.1 Place tripod with sampling equipment in the location indicated below.



Airflow direction

Place sampling stand ~ 1/4 of the total building length from the exhaust fans (e.g,. – 200 ft building length place sampling stand @ 50ft from the fans)

   2.2 Hang samplers on MANNEQUIN near breathing zone.

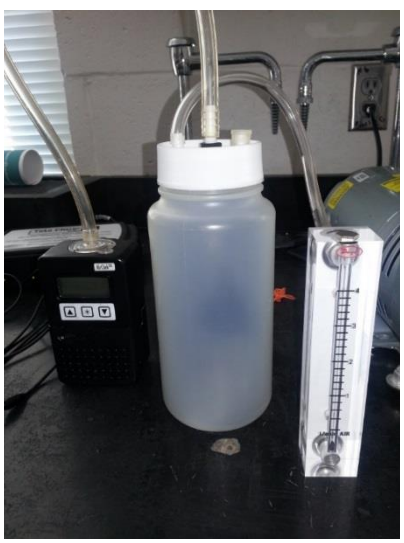
   2.3 ***Activate pumps and record time to the nearest $1/100^{th}$ of a second.*** (THIS IS VERY IMPORTANT)

2.5 Complete the field data collection sheet.

2.6 ***Pause pumps by pressing both "up" and "down" arrows simultaniously and record time to the nearest 1/100th of a second.*** (THIS IS VERY IMPORTANT)

V. Post calibration of air sampling equipment and sample storage.

1. Reassemble the calibration set-up for the inhalable sampler and activate the pump.



RECORD THE FLOW ON THE FIELD DATA SHEET

(This is very important)!

2. Disassemble the calibration set-up for the inhalable sampler and store sample.

VI. Field Blanks and Sample Storage (1 blank for every 10 samples)

1. During a field visit, simply remove the field bank samples from the storage container and place in the cooler with ice packs. Nothing more needs to be done with these samples.

2. Sample storage – Place samples in a small cooler with frozen ice packs. Ensure that the samples are stored securely to avoid shaking loose the dust in the samples.

3. When returning to the lab, place the samples in -20 degrees C for storage until shipment.

4. After 10 days of sampling, place samples in a cooler with frozen ice packs and ship FEDEX Overnight delivery to the following address:

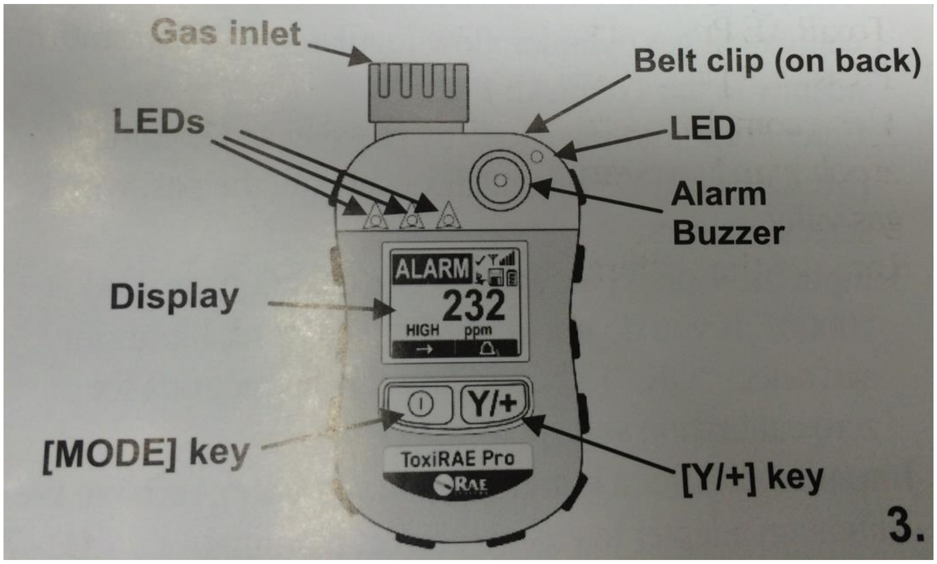
Dr. Matthew Nonnenmann
The University of Iowa
Institute for Rural and Environmental Health (IREH)
2420 Old Farmstead Road
Coralville, IA. 52241

PLEASE INDICATE ON THE PACKAGE THAT THE CONTENTS MUST BE FROZEN!

Also, please give me a call on my cell phone or send an e-mail to confirm that someone will be watching for the samples to arrive.

Matt Cell – 319-325-8051
matthew-nonnenmann@uiowa.edu

Ammonia: Using ToxiRAE Pro



Charging the Device:

Always fully charge the battery before use. While charging, the LED on the cradle glows RED. When the battery is fully charged, the LED glows GREEN.

To Charge:

- Place ToxiRAE Pro in charging cradle
- Device will lock into the cradle's latch
- The LED will light up on the cradle
- Connect AC adapter to charging cradle and plug it into power source.

If the batter is almost fully discharged, the message "Battery too low! Needs charging. Powering off!" shows in the display and the device shuts off. You must charge the battery before you can use the instrument!

Turning the Device ON:

- Press and hold [MODE] for 3 seconds.
- During startup, the battery, buzzer, vibration alarm, and LEDs are tested, and the device performs a self-test.
- When the main measurement screen appears, the devise is ready for calibration or use.

To sample:

- Turn device on
- Connect device to mannequin near breathing zone (10 inches from mouth).
- Device will collect data every 10 seconds

- **Read device's output after 15 minutes.**
- **Record amount of ammonia in ppm that is shown on screen.**
- **After sampling is complete, hit the [MODE] button and record the TWA, STEL, and Peak Value**
- This information shows results from the time the instrument was turned on.
- Press [MODE] twice.
- Instrument will prompt to stop measurement, press Y/+.
- Press [MODE] to exit.
- Turn instrument OFF.
- Take ToxiRAE off mannequin and charge.

Turning the Device OFF:

- Press and hold [MODE].
- A 5-second countdown to shutoff will begin.
- You MUST continue pressing the key for the entire shutoff process.
- If you remove your finger, the shutoff process is canceled and the device continues with normal operation.
- When the countdown beeps stop and you see "Unit Off," release your finger from the [MODE] key.
- The device is now off.

FOR QUESTIONS, REFER TO USER'S MANUAL PROVIDED.

APPENDIX B: DISTRIBUTION ANALYSIS

The Shapiro-Wilk test for normality was conducted to determine if the samples collected within each house were normal or log-normal. If the p-value of the test is less than 0.05 the population does not pass a normality test. Therefore, if the p-value was greater than 0.05, the population was considered normal. (Table B1).

The chi-square analysis was conducted to determine if the concentrations within the control house and treatment house had equal variances; this result was used to determine which t-test to conduct. The null hypothesis of the chi-square analysis is that there is no difference in distributions. If the calculated chi-square value is greater than the critical value then the null hypothesis is rejected. For this test the critical value is based on the degrees of freedom. Therefore, if the calculated value is less than the critical value, the null hypothesis is not rejected and the variances are assumed to be equal. In this study, the chi-square analysis was only conducted for the measured dust concentrations. The variance in ammonia concentrations collected within both houses were equal. (Table B2)

The Hind's weighted mean method for calculating count median diameter was used to evaluate the size-distribution of particles collected within each house using the OPC. Each sampling time in this study was treated as one sample (one sample with many data points). Although this analysis was completed by using a formatted Excel spreadsheet, the steps to this method are outlined below.

To Find Count Median Diameter:

1. Find average for count/liter for each bin channel.
2. Sum all average count/liter for all bin channels.

3. Multiply average count/liter/channel by mid-diameter for that channel. Complete this step for each channel.
4. Sum all values found in Step 3.
5. Divide the sum found in Step 4 by Sum found in Step 2.
6. Exponential of Value from Step 5 = Geometric Mean = Count Median Diameter for sample.

To Find Geometric Standard Deviation:

1. Calculate: Average count/liter/channel*(log(mid-diameter for that bin channel) - CMDStep5)^2. Complete this step for each channel.
2. Sum all values from Step 1.
3. Calculate: Square-root*(Result from Step 2 / (CMDStep2 – 1))
4. Compute: Exponential of value from Step 3.

Table B1. Shapiro-Wilk normality test for samples collected in each house.

House	Contaminant	p-value
Control	Inhalable Dust	< 0.05
	Inhalable Dust (log-normalized)	< 0.05
	Ammonia	< 0.05
	Ammonia (log-normalized)	< 0.05
Treatment	Inhalable Dust	< 0.05
	Inhalable Dust (log-normalized)	= 0.10
	Ammonia	< 0.05
	Ammonia (log-normalized)	< 0.05

Table B2. Chi-square analysis of variance between control and treatment houses.

Parameter	Result
Chi-square calculated value	1.68
Degrees of freedom	1
Chi-square critical value	3.84

APPENDIX C: DATA ANALYSIS

A t-test (independent two-sample assuming equal variances) was used to identify if there were differences in mean inhalable dust (Table C1) and ammonia (Table C2) concentrations within the two broiler chicken houses (treatment and control). The null hypothesis of this t-test is that the mean concentration in the treatment house was equal to the mean concentration in the control house. Therefore, if the p-value is greater than 0.05, the differences in means were not statistically significant.

Table CI. Comparison of log-normalized dust concentrations using t-test.

Parameter	Treatment House	Control House
Mean	1.740841049	1.826618088
Variance	0.164773841	0.251589343
Observations	54	54
PooledVariance	0.208181592	
Hyp. Mean Difference	0	
df	106	
t Stat	-0.976858752	
P(T<=t) one-tail	0.165431613	
t Critical one-tail	1.659356034	
P(T<=t) two-tail	0.330863227	
t Critical two-tail	1.982597262	

Table C2. Comparison of log-normalized ammonia concentrations using t-test.

Parameter	Treatment House	Control House
Mean	2.356969251	2.252304074
Variance	0.347933692	0.328949858
Observations	55	55
Pooled Variance	0.338441775	
Hyp. Mean Difference	0	
df	108	
t Stat	0.943466698	
P(T<=t) one-tail	0.173774022	
t Critical one-tail	1.659085144	
P(T<=t) two-tail	0.347548044	
t Critical two-tail	1.982173483	

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