Fall 2015

Effect of dust filtration control on CO2 and NH3 concentrations in a swine farrowing room

Richard Gassman
University of Iowa

EFFECT OF DUST FILTRATION CONTROL ON CO_2 AND NH_3 CONCENTRATIONS IN A SWINE FARROWING ROOM

by

Richard Gerard Gassman

A thesis submitted in partial fulfillment
of the requirements for the Master of Science
Degree in Occupational and Environmental Health in the
Graduate College of
The University of Iowa

December 2015

Thesis Supervisor: Associate Professor T. Renée Anthony

Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

_____

MASTER'S THESIS

_____

This is to certify that the Master's thesis of

Richard Gerard Gassman

has been approved by the Examining Committee for
the thesis requirement for the Master of Science degree
in Occupational and Environmental Health at the December 2015 graduation.

Thesis Committee: _____
T. Renée Anthony, Thesis Supervisor

_____
Diane S. Rohlman

_____
Brandi Janssen

ACKNOWLEDGEMENTS

There are many people who helped make this project a success. I would like to thank my advisor, Renée Anthony, whose support and guidance allowed me to reach farther than I ever would have thought possible. I want to thank my committee members, Diane Rohlman and Brandi Janssen. Your advice and encouragement mean the world to me. I would also like to thank my lab group. You accepted me into your fold and made this a very enjoyable and educational experience. To my fellow students, thank you for your advice, wisdom, and friendship. You will always be a part of my heart. Thank you also to the Mansfield swine education center at Kirkwood Community College for allowing me to conduct this project at their facilities. I would like to thank my children for standing by me through this process. Finally, I would like to thank my Wife Christina for your support, encouragement and love. It means more to me than you will ever know.

ABSTRACT

Swine workers in concentrated animal feeding operations (CAFOs) are at risk of developing respiratory illnesses as a result of exposure to a combination of ammonia (NH_3), carbon dioxide (CO_2), and dust. The purpose of this study was to determine whether the use of a recirculating ventilation system with a filter-type air pollution control (APC) unit (Shaker Dust Collector, United Air Specialists Inc.), selected to control dust, would inadvertently increase NH_3 and CO_2 concentrations in a farrowing room.

During the 2013-14 winter season, NH_3 and CO_2 concentrations were measured at six fixed locations throughout the farrowing room test site. Direct reading instruments (NH_3: VRAE, Rae Systems Inc.; CO_2: ToxiRAE Pro, Rae Systems Inc.) were deployed for 24-hour periods throughout the season on 18 randomly selected days. Contaminant concentrations were measured and compared by ventilation status (APC ON: 11 days, APC OFF: 7 days).

Ammonia concentrations were above the literature recommended limit (7 ppm) on 13 of the 18 sample days (72%) and even exceeded the threshold limit value (TLV) of 25 ppm on one of the sample days. Carbon dioxide concentrations exceeded the literature recommended limit of 1540 ppm on all 18 sample days, and average concentrations were half of the TLV (2500 ppm). There was no statistically significant difference in NH_3 ($p > 0.23$) or CO_2 ($p > 0.67$) when concentrations were compared by APC status.

The results of this study indicate a recirculating ventilation system with filter dust control does not increase NH_3 or CO_2 concentrations spatially or temporally in the room during operation. Future work will investigate engineering control options to reduce CO_2 concentrations in the farrowing room.

PUBLIC ABSTRACT

Swine workers are at risk of developing health problems due to breathing in air contaminants in swine barns. Methods have been developed to reduce the amount of contaminants a worker breathes. The purpose of this study was to determine whether a system intended to reduce dust concentrations would inadvertently increase ammonia and carbon dioxide concentrations, two contaminants commonly found in swine production facilities.

Ammonia and carbon dioxide concentrations were measured over the course of 18 randomly selected days throughout the winter of 2013-14, with the dust control system in operation (11 days) or not (7 days). Gas measuring instruments were positioned at six fixed locations throughout the study site. Gas concentrations were measured when the dust control device was in operation and compared with gas concentrations when the device was turned off.

In the farrowing room of our test swine barn, ammonia and carbon dioxide concentrations were not increased when the dust control device was in operation. Future work will explore effective control options to reduce high carbon dioxide concentrations that were identified in this field study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

Literature Review

Modern Swine Production

Hog production has seen dramatic changes over the last 30 years. In 1982, 315,095 U.S. farms sold 94,783,598 hogs compared to 55,882 farms selling 199,115,305 hogs in 2012 (2012 Census of Agriculture). This equates to an 82% reduction in the number of farms selling hogs and a 52% increase in the number of hogs produced. Also in 1982, the average number of hogs sold per farm was 300 compared to 3,563 hogs sold per farm in 2012 (2012 Census of Agriculture). The trend has been to move away from small family farming operations toward larger concentrated animal feeding operations (CAFO) (Honeyman, 1996). In the late 1970's and early 1980's, most hogs were produced in open lot or open building facilities with farrowing occurring in the late spring. Today, modern swine producers farrow year round. In the mid to late 1980's the agricultural community was hit with low commodity prices, escalating interest rates, and higher land prices that forced many producers out of business. This financial dilemma resulted in a large number of hog buildings sitting idle and provided an opportunity for larger producers to contract smaller growers to raise hogs for them. This contracting was mutually beneficial as it allowed the smaller operators to stay on their farms and reduced production costs for the larger producers.

Modern swine production in the CAFO operations can be classified into several production phases: breeding-gestation, farrowing (birthing), weaning, and finishing (EPA,

2015). In the breeding-gestation phase, the reproductive age female (sow) is placed into a holding pen with several other sows. A boar (reproductive age male) is placed with the sows with the purpose of inseminating the sows. The boar is rotated among several pens to assure the sows have been successfully inseminated. The sows are then sent to the gestation area where they are housed and fed until they are ready to farrow, typically 114 days. When the sow is ready to farrow, she is moved into the farrowing room. Modern farrowing rooms contain farrowing "crates" for the sows to birth in. The farrowing crates help reduce the number of piglet mortalities by preventing the sow from rolling over and crushing her piglets (EPA, 2015). The farrowing crates also allow for easier access to the sow and piglets by the producers. The sows are in the farrowing room until the piglets are weaned, typically 18-30 days (EPA, 2015). After the piglets are weaned from the sows, they are placed in a temperature-controlled nursery to acclimate to life without the sows. The piglets are kept in the nursery for a period of 6 to 10 weeks (EPA, 2015) until they are transferred to the finishing barns. The pigs remain in the finishing barn until they reach market weight.

Worker Tasks

Swine production workers perform a multitude of tasks in today's modern swine production facilities. The workers perform tasks such as: castration, vaccination, teeth clipping, tail docking, feeding, and cleaning. These tasks vary depending on the growth stage of the animals with proportionally more time spent in the farrowing barns tending to the young piglets and sows (O'Shaughnessy, 2010). These tasks expose the worker to multiple airborne contaminants in the barn. The swine workers are also exposed to ergonomic

hazards related to the tasks such as repetitive stress injuries, injuries to the lower extremities caused by contact with the swine, and slips, trips, and falls. In today's swine production facilities, these tasks are performed indoors.

CAFO Contaminants and Health Effects

Swine production workers are exposed to a variety of contaminants in today's modern swine facilities. Previous studies have shown an increase in the occurrence of respiratory inflammation, chronic bronchitis, and a decrease in lung function, such as FEV_1 as a results of exposure to these contaminants (Donham et al., 1989). The workers are exposed to irritant gases such as carbon dioxide (CO_2), carbon monoxide (CO), ammonia (NH_3), hydrogen sulfide (H_2S), and dust. These contaminants are generated from multiple sources within the swine facilities. Dusts containing dander and fecal material are released from the animal as well as animal feed. Ammonia and H_2S are released from the breakdown of organic material in the manure holding pits located under the floor of the production barns. Finally, CO and CO_2 are generated by heaters used to warm these buildings. Animal respiration also contributes CO_2 to the barn. In the cold weather months the swine facilities are closed up to reduce heating cost and to keep the swine comfortable. Reducing fresh air intake into the swine building causes the contaminant concentrations to increase over the winter season.

Carbon Dioxide

Carbon dioxide is a colorless, odorless gas that is a product of cellular respiration and the burning of fossil fuels (EPA, 2015). CO_2 is a simple asphyxiant that reduces the amount of oxygen available in the blood (NIH, 2015). Exposure to low concentrations (7.5%

- 10%) in the air of CO_2 can cause hyperventilation, blurred vision, and lung congestion (NIH, 2015). Exposure to high concentrations of CO_2 (>10%) can cause convulsions, unconsciousness, and death (NIH, 2015).

Carbon Monoxide

Carbon monoxide is a colorless, odorless gas emitted from incomplete burning of fossil fuels during the combustion process. CO causes harmful effects by reducing oxygen delivery to the body's vital organs and tissues. (Samet et al, 1987) Chronic exposures to low concentrations (> 9 ppm) of CO can cause symptoms such as headaches, dizziness, and nausea (Townsend and Maynard, 2002).

Ammonia

Ammonia at room temperature is a colorless gas with a highly irritating pungent odor (NYDOH, 2004). Ammonia is part of the nitrogen cycle and is generated as a product of the decomposition of organic matter. Exposure to low levels of ammonia (5-25 ppm) can cause eye irritation and coughing. Ammonia at higher concentrations of 5000-10,000 ppm can be fatal (Ryer-Powder, 2004).

Hydrogen Sulfide

Hydrogen sulfide is a colorless gas known for its pungent "rotten egg" odor at low concentrations. It is heavier than air and is a byproduct of the bacterial breakdown of organic matter (Guidotti, 1996). Concentrations of H_2S above 100 ppm can cause olfactory fatigue which inhibits the body's ability to detect the odor. Chronic exposure to low levels of

H_2S can lead to respiratory symptoms which include wheezing and shortness of breath (Legator et al, 2001).

Dust

Dust is generated in swine facilities from multiple sources, including animal feed, animal dander, and fecal material. Dusts can cause a wide range of health effects depending on where they deposit in the respiratory system. Inhalable dust (up to 100 μm) is able to enter the nose and mouth and can cause irritation in the upper respiratory tract (Iversen et al., 2000). Respirable dust (<10 μm) can penetrate deep into the lungs and cause an inflammatory reaction in the alveolar region (Malmberg, 1990).

Exposure Limits

Regulatory agencies and consensus groups have developed exposure limits based on health outcomes for individual contaminants. The Occupational Safety and Health Administration (OSHA) creates and enforces Personal Exposure Limits (PELs), which are eight-hour time-weighted averages (TWA) above which workers should not be exposed. They also include short-term exposure limits (STEL) and ceiling limits which provide a maximum exposure limit for periods of time shorter than an entire work shift. The American Conference of Governmental and Industrial Hygienists (ACGIH) is a consensus group that creates threshold limit values (TLV) for exposure to contaminants. Threshold limit values are based on contaminant levels an individual could be exposed to over a working lifetime without experiencing negative health effects. The National Institute for Occupational Safety and Health (NIOSH) conducts research and sets recommended exposure limits (RELs) for

workplace contaminants. Table 1 includes exposure limits for each individual compound found in swine barns.

Literature Recommended Exposure Limits

The literature suggests that agency and consensus group exposure limits for NH_3, CO_2, and dust may be too high for swine workers who are exposed to multiple compounds at the same time. Donham et al. (1989) conducted area sampling in a swine confinement setting, and the findings from this dose-response study indicated that an additive effect exists when workers are exposed to a combination of dust, CO_2, and NH_3. Health effects of NH_3 were found at lower concentrations in the presence of dust and CO_2 compared to CO_2 alone similar to recommendations for handling exposures to mixtures of the same health endpoints. Donham et al. recommended exposure limits of 7 ppm for NH_3, 1540 ppm for CO_2, and 0.23 mg/m^{-3} for respirable dust. Additional dose-response studies confirmed these exposure limits are reasonable (Donham et al., 1995; Reynolds et al., 1996).

Controlling CAFO Contaminants

Due to the known health effects associated with swine barn contaminants, controlling for these hazards is necessary. In order to effectively reduce contaminant exposure, control selection should be prioritized according to the hierarchy of controls. According to the hierarchy of controls, engineering controls, such as eliminating or substituting hazardous compounds, should be the highest priority. After engineering controls have been considered, administrative controls, such as rotating workers out of the hazardous environment, should be implemented. Personal protective equipment (PPE) is the last line of defense in the hierarchy of controls. PPE should only be used after other

options have been put into place and contaminant levels remain above levels that can cause negative health effects.

Several studies have investigated the effectiveness of control options for dust in swine CAFOs. Oil mists have been used to control dust with limited success. Rule et al. (2005) found that spraying with an oil-acid-alcohol mixture once per day reduced dust concentrations by 75-90% but had no control over NH_3 or CO_2.

Personal protective equipment is available to reduce exposure to dust, however studies show that PPE use is low among swine producers. In a survey of 301 swine producers, only 30% reported using filtering face piece respirators consistently (Zejda et al., 1993). Although effective at protecting producers from dust, filtering face piece respirators have little to no effect on reducing inhaled concentrations of NH_3 and CO_2.

Park et al. (2013) and Anthony et al. (2014) anticipated whether recirculating ventilation with various APC devices may reduce dust concentrations.

Objectives

While simulations of a recirculating ventilation system with air pollution control to filter out dust was identified as a potentially feasible recommendation, a field study was needed to evaluate these simulation findings. The objective of the overall study was to determine whether a ventilation system, with an air filtration unit and recirculation of the treated air back into the room, would effectively reduce dust concentrations without increasing concentrations of other contaminants in the room. This study focused on whether the system, deployed at a test site over a Midwestern winter, did not increase the concentrations of NH_3 and CO_2, while controlling for dust.

Table 1. Exposure limits for CAFO contaminants.

Agency	CO_2, ppm	CO, ppm	NH_3, ppm	H_2S, ppm	Respirable Dust, mg/m^3
OSHA (PEL)	5000	50	50	10	5
NIOSH (REL)	5000	35	35	10	N/A
ACGIH (TLV)	5000	25	25	10	3
Literature Recommended Limit*	1540	N/A	7	N/A	0.23

*Donham et al., 1989

CHAPTER II

Swine CAFO Evaluation

Introduction

Hog production has seen dramatic changes over the last 30 years. In 1982, 315,095 U.S. farms sold 94,783,598 hogs compared to 55,882 farms selling 199,115,305 hogs in 2012 (2012 Census of Agriculture). This equates to an 82% reduction in the number of farms selling hogs and a 52% increase in the number of hogs produced. Also in 1982, the average number of hogs sold per farm was 300 compared to 3,563 hogs sold per farm in 2012 (2012 Census of Agriculture). In 1982, the average producer raised swine in either an open lot or in an open front swine building. Today the modern producer raises swine in a concentrated animal feeding operation (CAFO). On average, these facilities now contain over 5000 head of swine. In the old way of producing swine, outside air diluted contaminants generated from swine and feed. Modern swine CAFOs have limited ventilation with fresh air and are typically sealed during the winter months to reduce heating costs and to provide a warm and dry environment for the swine. Contaminants can accumulate in CAFOs during the winter months, putting workers at risk of developing respiratory illnesses. Workers spend the most time in farrowing units, where they are involved in a wide range of tasks such as clipping tails, administering vaccinations, and notching ears. Workers may spend their entire workday in these farrowing units potentially exposing them to higher concentrations of the contaminants.

Studies have observed airflow obstructions, bronchial inflammation, and declines in lung function among swine CAFO workers as a result of exposure to swine barn

contaminants (Rylander et al., 1990; Donham et al., 1991; Malmberg and Larsson, 1993; Pedersen et al., 1996; Senthilselvan et al., 1997 Radon et al., 2001; Cormier and Israel-Assayag, 2004). Decreased respiratory health has been shown to be associated with a mixture of swine barn contaminants, including dust, NH_3, and CO_2. Exposure limits have been developed for individual CAFO contaminants by regulatory agencies and consensus groups. Although these limits exist, they do not take into account the additive effect of swine CAFO contaminants when they are combined. Donham et al. (1989) proposed that due to the additive effect of the complex mixture of dust, NH_3, and CO_2 found in swine CAFOs, more conservative exposure limits should be adopted.

Swine barn contaminants are generated from multiple sources. Dust in swine barns are comprised of swine feed, fecal material, and dander. Larger sized inhalable particles (up to 100 micrometers) can cause irritation in the upper respiratory system (Iversen et al., 2000). Smaller respirable particles (< 10 μm) can deposit in the alveoli when inhaled, causing an inflammatory response (Malmberg, 1990). The breakdown of swine fecal material, urine, and feed releases NH_3 as a byproduct. This contaminant has a pungent odor, can cause respiratory and eye irritation at exposures above 25 ppm, and can be fatal at concentrations above 5000 ppm (Ryer-Powder, 2004). Carbon dioxide is generated from swine respiration and heater exhaust. This odorless, colorless gas can cause asphyxiation when found at concentrations above (100,000 ppm). At concentrations above 5000 ppm symptoms may include headaches, dizziness, and malaise (NIH, 2015).

Contaminant concentrations may vary depending on a variety of factors. The type of feed and feeding system used, the level of swine activity, and housekeeping practices can

influence the amount of contaminants generated. O'Shaughnessy et al. (2010) found CAFO contaminants varied by number of swine, by ventilation amount, and by outdoor temperature. Temporal contaminant variation may occur due to the outdoor temperature fluctuations associated with time of day. During colder time periods (e.g., evenings when the sun is not heating the building) increased heater operation is required to maintain temperatures necessary for swine health, producing more CO_2 than would be produced during warmer time periods. The increase in CO_2 caused by heater operation may be offset by decreased swine activity (respiration) during the nighttime when pigs are sleeping. Spatial variations may also exist if contaminant sources are concentrated in a specific area of a room due to increased airflow and changes in air distribution. Reeve et al. (2013) observed spatial variations as well as differences by pit fan status: contaminant concentrations were higher when pit fans were not in operation.

Due to the known health effects associated with exposures to swine barn contaminants, methods to control contaminant sources should be explored. Currently limited options exist for controlling gaseous contaminants such as NH_3 and CO_2. Studies have shown that misting with oil droplets is effective in reducing dust concentrations in swine CAFOs (Rule et al, 2005). Filtering face-piece respirators have also been shown to reduce the amount of dust inhaled by swine workers. Unfortunately respirator use rates are low in swine confinement settings (Rule et al, 2005). Recirculating ventilation with air pollution control devices have been modeled to be effective at reducing dust concentrations (Anthony et al., 2014). However, actual field testing is necessary to confirm the viability of these units. Field testing is also necessary to confirm these units do not

increase NH_3 and CO_2 concentrations with the increased air flow across the manure pits.

This work will examine the impact of a recirculating ventilation system, with dust filtration control, by evaluating room concentrations of ammonia and carbon dioxide. Evaluations will be made to ensure concentrations do not increase as a result of increased airflow from the ventilation system. Additionally, assessments will be made to ensure there was no difference in concentrations temporally or spatially as a result of the intervention.

Methods

Test Site

This study was conducted at the Mansfield Swine Education Center located at Kirkwood Community College, Cedar Rapids Iowa. The Mansfield Swine Education Center is a farrow to finish swine operation that is used to educate students in all aspects of modern swine production. It is similar in style and scope to the hog production systems used by modern hog producers. The 19-sow capacity farrowing room measured 9.2 m x 14 m and contained three rows of five 1.5 m x 2.4 m crates and one row of four 2 m x 2.4 m crates that run east to west (Figure 1). Crates were positioned above two 0.9 m deep pull-plug manure pits. The manure pits were vented with two fans along the west end of the pit: both pit fans were operated continuously throughout this study period. Two exhaust fans were mounted on each north and south wall to provide ventilation during the warmer months: these fans were closed for the duration of this experiment to conserve heat. Two pressure sensitive louvers were positioned on the east wall of the farrowing room to allow air from the hall way to enter the farrowing room. Eight pressure activated louvers (RayDot Industries, Cokato, MN) were positioned in the ceiling over the center aisle to allow attic air

to enter the farrowing room: these vents were closed and sealed for the duration of this study.

Ventilation System

An air pollution control unit with dust filtration (Shaker Dust Collector [SDC], model SDC-140-3, United Air Specialists, Inc., Cincinnati, OH) was installed to lower dust concentrations (Figure 2). The unit was placed along the outside west wall of the farrowing room (Figure 1) and operated at an airflow rate of 1000 cfm. Air was drawn from the farrowing room through two 8-inch galvanized ducts and passed through the SDC's 14-pocket polyester filter (United Air Specialists, Inc.). Clean air was returned into the farrowing room through a 10-inch duct, where the volume was then split into two halves and dispersed through two 10-inch fabric diffusers.

Sampling Strategy

Sampling occurred on 18 days, randomly selected, from December 13, 2013 through February 27, 2014. Baseline concentrations were measured over three days prior to turning the ventilation system on (Dec 13-19), then the system remained on for one month (APC ON, Dec 21-Jan 21, 6 sample days). Midway through the study, the system was turned off (APC OFF, Jan 22-27, 3 sample days) then was turned back on for another month (Jan 28-Feb 25, 5 sample days). At the end of the study, the system was turned off (Feb 26-27, 1 sample day). Prior to each scheduled sampling day, the system was turned on or off at least 24-hours in advance to allow the concentrations in the room to equilibrate.

Sampling Equipment

Direct reading gas samplers were deployed at six locations within the farrowing building, marked A through F (Figure 1). Six VRAE multi-gas monitors (Model 7800, Rae Systems Inc., San Jose, CA) were used to measure ammonia (NH_3), hydrogen sulfide (H_2S), oxygen (O_2), lower explosive limit (LEL), and carbon monoxide (CO). An external filter was placed on the inlet of the VRAE to protect the sensors from dust contamination, in conformance to manufacturer's recommendations. Six ToxiRAE Pro single-gas monitors (Model 1850, Rae Systems Inc., San Jose, CA) were used to measure carbon dioxide (CO_2). Both the VRAE and the ToxiRAE we set to log every 60 seconds, resulting in 1440 one-minute averages over each 24-hour sampling period. To ensure sufficient power for 24-hour monitoring, each monitor was operated while connected to power within the room. These monitors were placed in baskets, suspended from the ceiling (Figure 3), at each of the six monitoring locations, A through F, as indicated in Figure 1. The inlets to each monitor were positioned at a height of 1.5 m above the floor (breathing zone), using reference poles affixed to the animal crates throughout the study duration to ensure repeatable monitor position. Prior to deployment, all equipment was calibrated in the lab following manufacturer recommendations. Multi-gas VRAE monitors were first exposed to fresh air then calibrated with a span gas (NH_3 = 25ppm, H_2S = 25ppm, O_2 = 20.9%, LEL = 50%, CO = 50 ppm).

The equipment was transported to the test site, turned on, and placed side-by-side in the hallway (colocated), while datalogging, for at least 10 minutes. Next, while still datalogging, the monitors were positioned in the test room for the 24-hour sample period.

After sampling, the monitors were again colocated in the hallway, for at least 10 minutes, to allow an assessment of sensor drift that may have occurred over the test period. Equipment was systematically shut down and returned to the lab for data download and post-calibration.

Throughout the study, monitors were deployed by 8:30 AM and retrieved around 9:00 AM the following morning. At the time of deployment and retrieval, descriptive data including the number of sows, number of piglets, room temperature, and number of heat lamps in operation, and changes to the ventilation system (ceiling louvers, wall fans, position of doors/louvres between room and hallway) were observed and recorded. Weather data was obtained from the NOAA weather center located at The Eastern Iowa Airport in Cedar Rapids, Iowa 2.9 miles from the test facility.

Data Analysis

In the farrowing barn, collocation of data-logging equipment was performed prior to and immediately following deployment of monitors to evaluate and correct for sensor drift over the 24-hour sampling period. A sensor drift was defined as being greater than 100 ppm for CO_2 and greater than 1 ppm for NH_3. When a sensor drift was identified, the drifted sensor data was adjusted to the mean of the colocation data using linear regression, then plotted to verify the adjustment was reasonable.

Descriptive statistics were generated for contaminant production factors (swine and piglet count, outdoor temperature). One-minute concentrations were used to compute 24-hour averages as well as three 8-hour shift averages, with Shift 1 from 8:30 am to 4:30 pm, Shift 2 from 4:30 pm to 12:30 am, and Shift 3 from 12:30 am to 8:30 am. Concentration and

log transformed concentration data were assessed for normality using the Shapiro-Wilk normality test. To determine if contaminant concentrations differed by APC status, a one-way ANOVA test was used. To determine if contaminant concentrations differed by shift or position, Tukey-Kramer multiple comparison tests were used. For data that were not normally distributed, non-parametric Wilcoxon tests were used. All data were analyzed using SAS (Version 9.3, SAS Institute Inc., Cary, NC, USA). One-way ANOVA tests were performed to ensure contaminant concentrations did not increase with the APC on. Temporal assessments were made to ensure the intervention was effective regardless of temporal factor differences (e.g., temperature, swine activity). Spatial assessments were made to ensure the ventilation system effectively distributed air throughout the room, without leaving pockets of high and low contaminant concentrations.

Results

Descriptive

Details on the production factors over the study period are given in Table 2, by APC status. There were no significant differences in production factors by APC status.

Figure 4 illustrates the 24-hour room averaged NH_3 concentrations, by study day. Thirteen out of 18 sample days (72%) exceeded the literature recommended limit of 7 ppm. The mean NH_3 concentration with the APC off was 8.6 ppm. The mean NH_3 concentration with the APC on was 10.9 ppm. Figure 5 illustrates the CO_2 concentrations, averaged over all positions over 24-hours, also by study day. Concentrations exceeded the 1540 ppm literature recommended limit on every sample day. The season average CO_2 concentration was 2500 ppm, which is 50% of the ACGIH TLV of 5000 ppm. During the course of the

season both NH_3 (Figure 4) and CO_2 (Figure 5) concentrations steadily increased regardless of APC status.

Descriptive statistics (mean, SD) for NH_3 concentrations are provided in Table 3. The 8-hour average NH_3 concentrations, by position (bolded), were not normally distributed, nor were the log transformed data. Non-parametric Wilcoxon tests were performed for those data sets that were not normal after log transformation. For all normally distributed data sets, the Tukey-Kramer test was sufficient.

Descriptive statistics (mean, SD) for CO_2 concentrations are provided in Table 4. The 8-hour CO_2 concentrations with the APC turned on were not normally distributed (bolded). The log transformed data were also not normally distributed. For the data set that was not normal after log transformation, the non-parametric Wilcoxon test was used. The Tukey-Kramer test was used for all other normally distributed data sets.

Differences by APC Status

The one-way ANOVA tests found no differences in NH_3 concentrations by ventilation status ($p > 0.23$). There were also no differences in CO_2 found by ventilation status ($p > 0.67$).

Differences by Shift

A difference in NH_3 concentrations by shift was observed when the APC was turned off ($p < 0.04$), but no difference was found when the APC was turned on ($p > 0.21$). Shift 3 had higher concentrations than Shift 1 and Shift 2. When the APC was turned off, there was no difference in CO_2 concentrations by shift ($p > 0.69$) or with the APC on ($p > 0.42$).

Differences by Position

For 8-hour concentration averages, there was no statistically significant difference observed by position for NH_3 when the APC was turned off ($p > 0.24$). There was a statistically significant difference noted by location for NH_3 when the APC was turned on ($p < 0.02$). Multiple-comparison tests identified that the concentrations at position D, close to the operating heater, were significantly higher than those by position F, close to the open door to the hallway. For 24-hour averages, there was no statistically significant difference in NH_3 concentrations across the room when the APC was turned off ($p > 0.45$) or on ($p > 0.43$).

Eight-hour CO_2 concentrations did not vary by position with the APC off ($p > 0.07$), but concentration differences were identified with the APC on ($p < 0.01$). Position F, located by a mostly-opened door to the building's hallway, had significantly higher CO_2 concentrations, and although not statistically significant, was higher with the APC off as well. Twenty-four hour positional data showed no significant difference in CO_2 concentrations by position when the APC was turned off ($p > 0.58$) or on ($p > 0.23$).

Discussion

There was no significant difference in NH_3 or CO_2 concentrations noted when the APC was turned on compared to when the APC was turned off. These results indicate the recirculating ventilation system with filtration dust control did not increase contaminant concentrations for these gases.

This study also examined whether there were differences in contaminant concentrations by shift. Concentrations of NH_3 were higher during Shift 3 compared to Shift

1 and Shift 2. This may have been attributable to lower outdoor temperatures during the overnight shift (3).

In addition, this study examined whether the ventilation system intake and return air distribution systems negatively impacted room contaminant concentrations, specifically whether localized high concentrations of NH_3 or CO_2 were generated using this system. Spatial assessments confirmed that there were no localized high or low concentrations of contaminants throughout the farrowing room. Positioning the return air diffusion ducts along the ceilings of the two head-aisles to return treated air resulted in a reasonably uniform distribution of these two contaminants. Farmers are encouraged to adopt recirculating ventilation with a dust filtration device to improve the air quality of swine confinement facilities. When comparing production factors (Table: 2) the values are comparable for APC on and APC off. This lack of difference further supports the argument that the intervention does not increase CO_2 or NH_3 concentrations. Contaminant concentrations found in the test site are similar to concentrations found at other swine facilities (Sun et al, 2010, Rahman et al, 2011, Jerez et al, 2005) supporting the argument that the intervention may be effective at reducing dust concentrations at similar swine farrowing facilities without increasing NH_3 or CO_2 concentrations.

Limitations

This study was conducted at a single farrowing room at the Mansfield Swine Education Center. Commercial farrowing rooms tend to be larger than the farrowing room where the study was conducted. The Mansfield Swine Education Center facility is similar in design to other farrowing rooms used by hog producers in the Midwest. Because of the

similarities to these other rooms the use of an APC in other rooms should produce similar results. The heaters used in in the farrowing room of the Mansfield Swine Education Center are similar to the heaters used in many of the farrowing rooms in the Midwest. The results indicate that a portion of the CO_2 concentrations in the room were attributed to these heaters. By utilizing a new heater type that vents combustion gases to the outside the CO_2 concentrations in the farrowing room could be reduced.

Conclusion

The results of the data show that operating a recirculating ventilation system, with dust filtration device, did not adversely affect the concentrations of NH_3 or CO_2 in the farrowing barn. There was also no significant difference in the NH_3 or CO_2 concentrations by position when using 24-hour averaged data. While additional research is needed to evaluate methods to reduce gases, these results indicate that recirculating ventilation with a filtration unit may be a feasible solution to lower dust concentrations and does not increase NH_3 or CO_2 concentrations.

Table 2. Descriptive statistics for production factors by APC status.

	APC ON		APC OFF	
Outdoor Temperature ^{o}C	-9.6	(7.2)	-8.5	(6.9)
Sow Count	14.6	(4.3)	13.1	(2.3)
Piglet Count	68.2	(43.1)	69.4	(17.7)

Table 3. Eight-hour and 24-hour NH_3 results.

Comparison		APC	n	Mean ppm	SD ppm	P (Tukey-Kramer Multiple Comparison)	P (Wilcoxon Non-parametric Test)
Shift	1	Off	37	7.4	3.23		
	2	Off	37	8.7	3.83	<0.04	
	3	Off	37	9.8	4.80		
	1	On	57	9.2	6.36		
	2	On	57	11.3	9.45	>0.21	
	3	On	54	12.2	11.06		
Position (8-hour)	A	Off	18	10.3	4.97		
	B	Off	21	8.9	5.23		
	C	Off	18	8.3	3.04		
	D	Off	21	9.4	3.42	**>0.24**	
	E	Off	21	8.1	3.42		
	F	Off	12	5.6	2.51		
	A	On	32	10.8	8.22		
	B	On	33	10.2	7.47		
	C	On	29	10.9	5.89		**<0.02**
	D	On	27	14.6	15.05		
	E	On	32	11.0	8.40		
	F	On	15	5.3	4.05		
Position (24-hour)	A	Off	6	10.3	4.76		
	B	Off	7	8.9	5.26		
	C	Off	6	8.3	2.84		
	D	Off	7	9.4	3.43	>0.45	
	E	Off	7	8.1	3.43		
	F	Off	4	5.6	2.70		
	A	On	11	10.6	8.14		
	B	On	11	10.2	7.47		
	C	On	10	11.1	6.01	>0.43	
	D	On	9	14.6	14.66		
	E	On	11	11.1	8.31		
	F	On	5	5.3	4.34		

Bolded values indicate data was not normally distributed.

Table 4. Eight-hour and 24-hour CO_2 results.

Comparison		APC	n	Mean ppm	SD ppm	P (Tukey-Kramer Multiple Comparison)	P (Wilcoxon Non-parametric Test)
Shift	1	Off	42	2450	370		
	2	Off	42	2400	350	>0.69	
	3	Off	42	2464	390		
	1	On	65	2480	340		
	2	On	65	2480	350	>0.42	
	3	On	62	2560	380		
Position (8-hour)	A	Off	21	2467	390		
	B	Off	21	2353	392		
	C	Off	21	2345	373		
	D	Off	21	2423	332	>0.07	
	E	Off	21	2379	324		
	F	Off	21	2653	357		
	A	On	33	2550	361		
	B	On	33	2367	345		
	C	On	31	2435	359		**<0.01**
	D	On	30	2544	323		
	E	On	33	2466	319		
	F	On	32	2693	367		
Position (24-hour)	A	Off	7	2466	382		
	B	Off	7	2353	383		
	C	Off	7	2345	360		
	D	Off	7	2422	316	>0.58	
	E	Off	7	2378	315		
	F	Off	7	2653	344		
	A	On	11	2551	350		
	B	On	11	2367	336		
	C	On	11	2415	364	>0.23	
	D	On	10	2544	313		
	E	On	11	2458	329		
	F	On	11	2696	354		

Bolded values indicate data was not normally distributed.

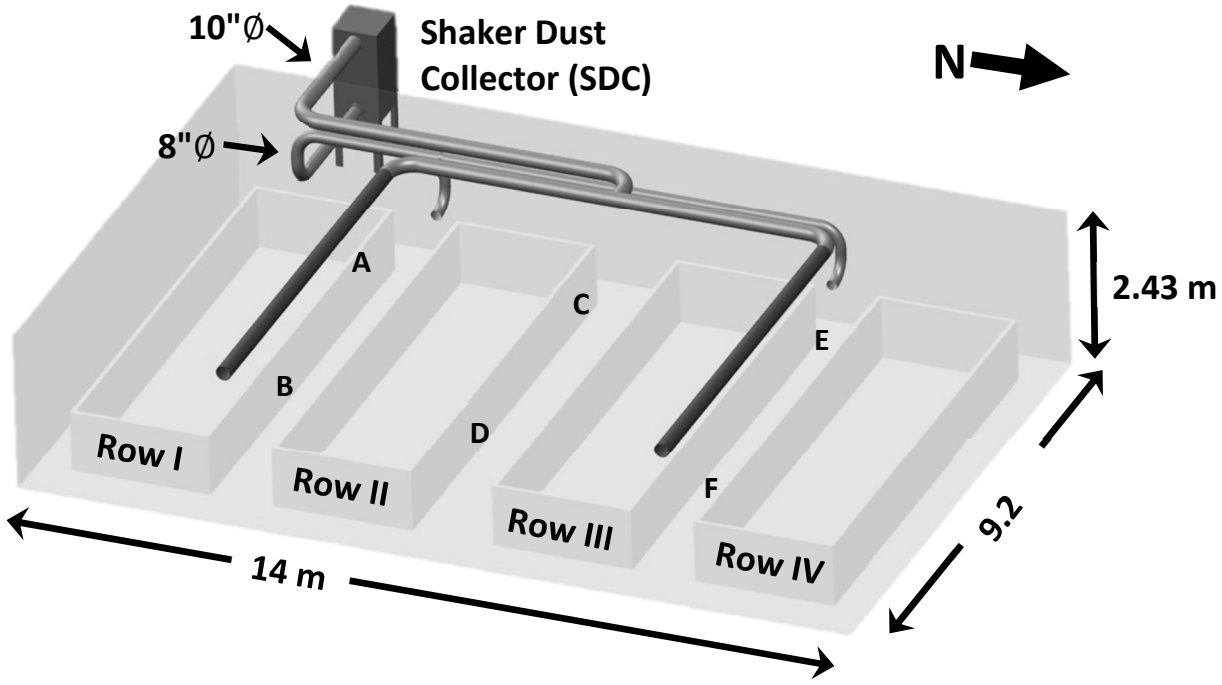


Figure 1. Test room layout.

Figure 2: Shaker Dust Collector (SDC) with annotations.

Figure 3: Direct-reading instrument deployment at Position A. Inlets of instruments were positioned 1.5 m from the floor. The ToxiRAE was attached to the pole. The VRAE was hung in a basket and the instrument tubing was fed through a bolt fastened to the pole.

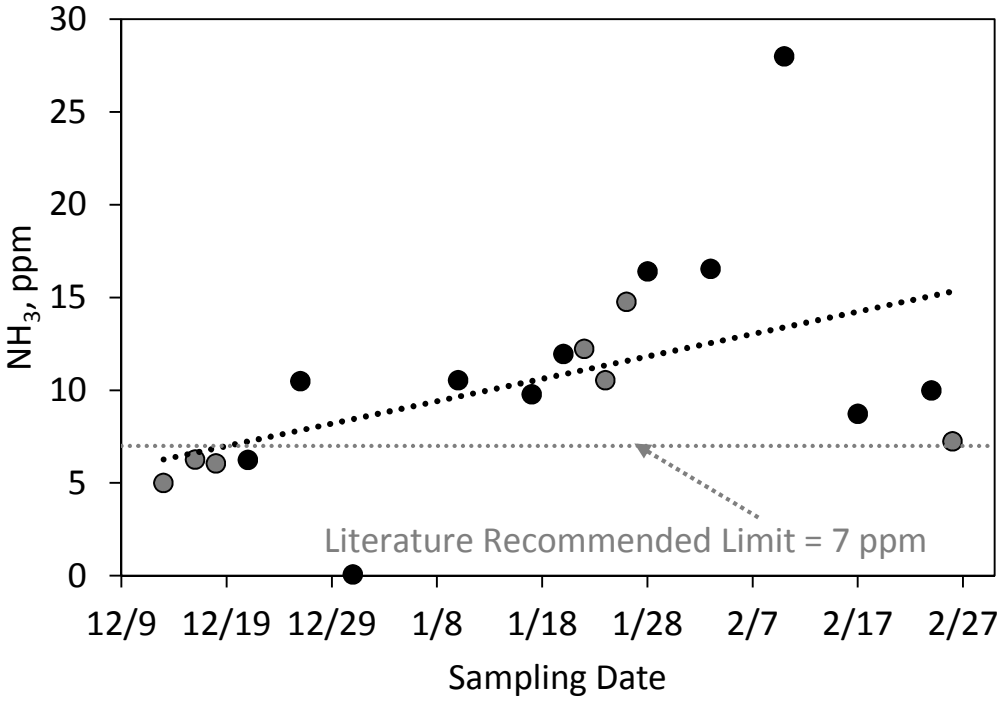


Figure 4. 24-hour average NH_3 concentrations.

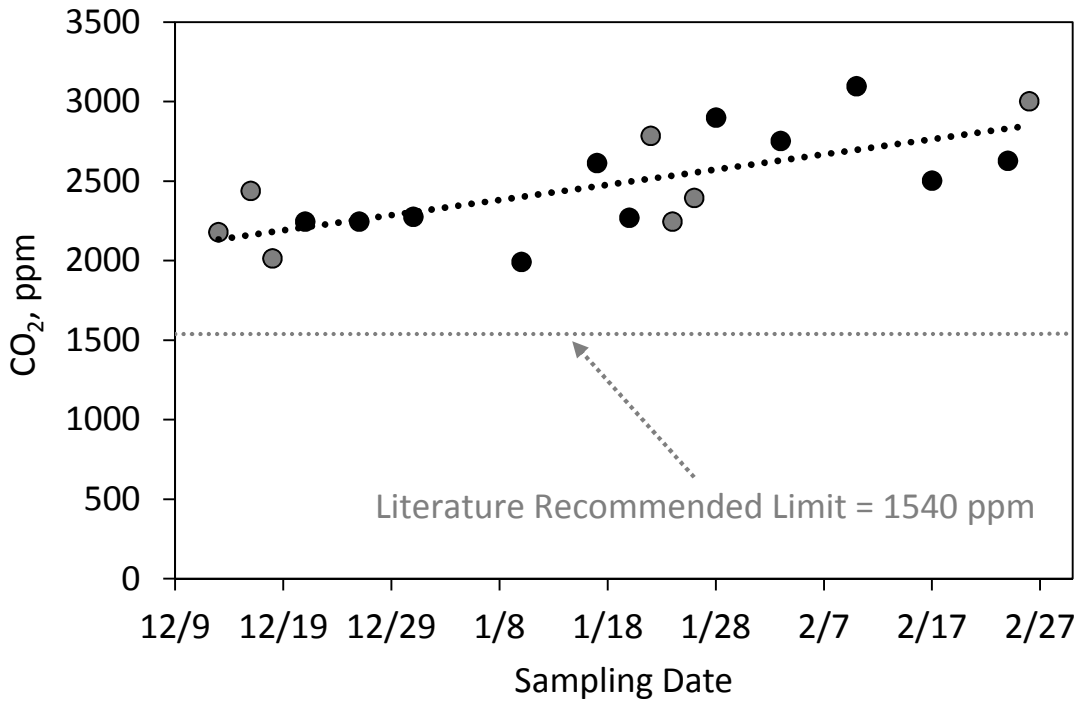


Figure 5. 24-hour CO_2 concentrations.

CHAPTER III

Conclusions

In the past 30 years the swine industry has been transformed from many farms producing a few hogs to a few farms producing large numbers of hogs. In an effort to improve swine health and create production efficiencies the industry has adopted concentrated animal feeding operations (CAFO), which have increased in size and number of animals. While this consolidation into larger CAFOs has increased the efficiencies of swine production it has also come with an increase in the health risks of the workers in these facilities. During the winter months these facilities are sealed from the outside to reduce the cost of heating the building to temperatures that optimize swine growth. This leads to a decrease in the amount of fresh air entering the confinement facilities which can lead to an increase in the concentrations of CO_2 and NH_3 in the facilities. Ammonia from the decomposition of the swine manure, carbon dioxide from the respiration of the swine and the combustion of fuel in the heaters combined with the dust in the facilities can lead to a decrease in lung function (Donham et al. 1989).

During the course of this study it became apparent that the environment inside the farrowing room was not the ideal place for sampling instruments. Colocation of the instruments prior to deployment and immediately following the sample period was vital to the study to account for sensor drift during the sample period. Several of the instruments failed and had to be removed or replaced. Due to the 24-hour sampling period, extension cords were needed to provide continuous power to the instruments. These same extension cords were also needed by the producers to provide power to heat lamps for the piglets,

which resulted in several instances of incomplete data caused by the unplugging of the instruments.

In production agriculture, control options to protect workers continues to focus almost exclusively on the use of PPE to protect swine workers from contaminants. However in a survey of 1493 Midwestern Farmers less than 3% reported using PPE always or most of the time (Carpenter et al, 2002). The use of a recirculating Air Pollution Control device (APC), an engineering control, has the potential to reduce dust concentrations in swine farrowing barns without increasing the cost of heating the room.

CO_2 concentrations increased throughout the length of the study. The APC recirculates the room air and does not exhaust the contaminated air to the outside. One explanation could be the non-vented heaters used in the farrowing room during this study contribute to the CO_2 concentrations in the room. Position F, which was next to a door that opens to the hallway had the highest concentrations of CO_2 throughout the study. During the course of the study it was determined that the heater in the hallway was faulty. The use of heaters that vent combustion gases could reduce the CO_2 concentrations and is being studied by Yang et al, 2015.

During the course of this research project the author learned several important lessons that are vital to any student involved in a research project: Be prepared for anything that can happen because it probably will. Do not be afraid to ask questions to gain a better understanding of the scope of the project. Do not let your fears hold you back. Do not procrastinate on writing as it does not get any easier the farther out you get. The Professors are here to help us and they really do want us to succeed. Take the time to get to know

your Advisor. They are not as scary as some would lead you to believe. When sampling in a swine farrowing barn always keep the lid closed on your coffee cup to avoid unwanted surprises. Apparently flies like coffee too. Finally enjoy the experience and get as much out of it as you can.

Appendix A. Standard Operating Procedures for ToxiRAE Pro Monitor

Lab Calibration for ToxiRAE Pro CO_2

1. Turn on ToxiRAE Pro CO_2 , Hold **[Θ]** until machine beeps
2. Wait until finished initializing (~ 1 min)
3. Press **[Θ]** and **[Y/+]** simultaneously to enter ToxiRAE settings
4. Enter Password **0000**
5. Enter Calibration menu
6. Enter Zero Calib
7. Attach calibration adaptor to top of ToxiRAE Pro CO_2
8. Attach valve onto Nitrogen Calibration Gas, connect hose between Cal gas and calibration adaptor
9. Twist knob on valve all the way open
10. Press start on ToxiRae
11. Allow calibration to finish (~90 seconds)
12. Twist knob on valve to off position
13. Remove valve from Nitrogen Cal gas and store away
14. Enter Span Calib
15. CO_2 ppm should be set to **25000**
16. Attach valve onto CO_2 Calibration Gas
17. Twist knob on valve all the way open
18. Press start on ToxiRae
19. Allow calibration to finish (~90 seconds)
20. Twist knob on valve to off position
21. Remove valve from CO_2 Cal Gas and store away.
22. Exit Calibration
23. Exit Settings
24. Shut down ToxiRae by holding **[Θ]** for 5 seconds
25. Place ToxiRae back in cradle
26. Machine is ready to collect data

Field Procedure for starting ToxiRae

1. Turn on ToxiRae, Hold **[Θ]** until machine beeps
2. Wait until ToxiRae is finished initializing (~ 1 min)
3. Start colocation SOP

Field Procedure for ending ToxiRae

1. Turn off ToxiRae by Holding **[Θ]** 5 seconds

Bump Test for ToxiRae (Back in Lab)

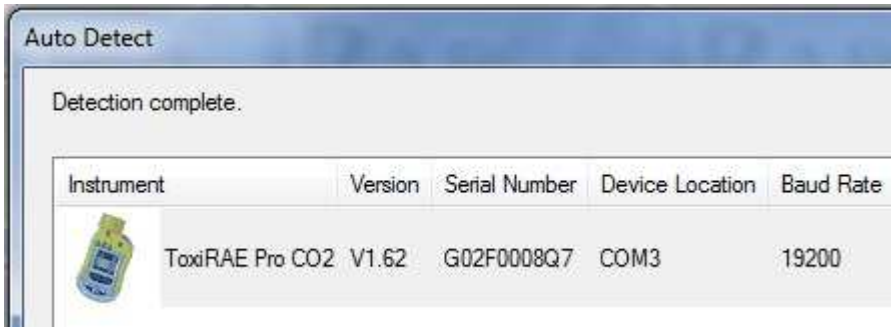
1. Turn on ToxiRAE Pro CO_2 , Hold **[Θ]** until machine beeps
2. Wait until finished initializing
3. Attach calibration adaptor to top of ToxiRAE Pro CO_2
4. Attach valve onto CO_2 Calibration Gas
5. Twist knob on valve all the way open
6. Allow gas to flow for 90 seconds
7. Write down value
8. Twist knob on valve to off position
9. Remove valve from CO_2 Cal Gas and store away.
10. DO NOT TURN OF TOXIRAE, WILL PULL DATA OFF IN NEXT STEPS

Pulling data off ToxiRae

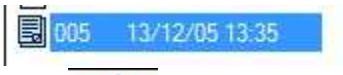
1. Press **[Θ]** until "Enter Communications and stop measurement?" screen
2. Press **[Y/+]** to enter communication mode
3. Place ToxiRae in cradle
4. Connect cradle to computer
5. Enter ProRAE Studio II 

6. Press Administrator, Password is: rae

7. Click AutoDetect 
8. Double click the instrument



9. Click Datalog 

10. Click Download All Data 
11. Click Event that contains barn data
    a. This will be the event with the data and time from when the ToxiRae started logging



12. Click Export
13. File Directory: Desktop -> Swine Barn Data Downloads - Raw -> “Start Date” -> ToxiRae
14. Change file type to .csv
15. Name file: *ToxiRae_DeviceID_Date* (example of data collected on device TRB on December 7, 2013: ToxiRae_TRB_120713.csv)
16. Copy data to flash drive
17. Delete all datalog files on device 
    a. Files will not disappear; to check if they are deleted go through steps 7-10, a pop up should appear saying “No datalog record.”
18. Press **[Θ]** to exit
19. Hold **[Θ]** for 5 seconds to power down ToxiRae

Appendix B. Standard Operating Procedures for VRAE Multi Gas Monitor

Lab Calibration for VRae

1. Turn on VRae, Hold **[MODE]** until machine beeps
2. Wait until VRae is finished initializing
3. Attach inlet adapter to VRae
4. Press and hold both **[MODE]** & **[N/-]** to enter programming mode
5. Enter "Calibrate Monitor?" with **[Y/+]**
6. Enter "Fresh Air Calibration" with **[Y/+]** (use air in lab as the zero point)
7. Allow zero calibration to occur
8. "Zero cal done reading =" will flash along with values for the sensors
9. Enter "Multiple Sensor Calibration?" with **[Y/+]**
10. CO, H_2S, LEL, and OXY will be shown
11. Attach hose and pressure valve to inlet of *Cal Gas 1 (Mixed gas)*
12. Slowly twist Calibration Gas Cylinder into valve until pressure reads on valve
    a. If VRae alarm ᴸPump goes off. Press **[Y/+]** to resume pump function
13. Hit **[Y/+]** to start calibration
14. Allow gas to flow into VRae until equilibrates (~30-90 sec)
15. Slowly untwist Calibration Gas Cylinder and store away
16. Attach pressure valve to *Cal Gas 2 (Ammonia)*
17. Enter "Single Sensor Calibration?" with **[Y/+]**
18. Check to see if NH_3 has a _ after it (this means that it is selected).
19. Slowly twist Calibration Gas Cylinder into valve until pressure reads on valve
    a. If VRae alarm ᴸPump goes off. Press **[Y/+]** to resume pump function
20. Press **[Y/+]** to begin calibration of ammonia
21. Press **[MODE]** to exit programming mode
22. Turn of device by holding **[MODE]** for 5 seconds

Field Procedure for starting VRae

4. Turn on VRae, Hold **[MODE]** until machine beeps
5. Wait until VRae is finished initializing
6. Place in basket

Field Procedure for ending VRae

2. Turn off VRae by Holding **[MODE]** 5 seconds

Bump Test for VRae

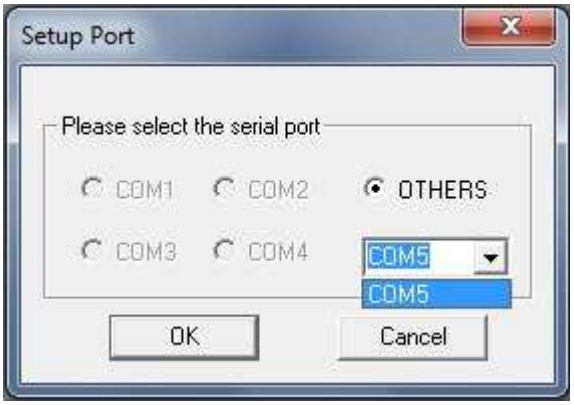
1. Turn on VRae, Hold **[MODE]** until machine beeps
2. Wait until VRae is finished initializing
3. Attach inlet adapter to VRae

4. Attach hose and pressure valve to inlet of *Cal Gas 1 (Mixed gas)*
5. Slowly twist Calibration Gas Cylinder into valve until pressure reads on valve
    a. If VRae alarm ┗Pump goes off. Press **[Y/+]** to resume pump function
6. Allow gas to flow into VRae for 2 minutes
7. Slowly untwist Calibration Gas Cylinder and store away
8. Attach pressure valve to *Cal Gas 2 (Ammonia)*
9. Slowly twist Calibration Gas Cylinder into valve until pressure reads on valve
    a. If VRae alarm ┗Pump goes off. Press **[Y/+]** to resume pump function
10. Allow gas to flow into VRae for 2 minutes
11. Slowly untwist Calibration Gas Cylinder and store away
12. DO NOT TURN OF VRAE, WILL PULL DATA OFF IN NEXT STEPS

Pulling data off VRae

1. Press **[MODE]** until "Communcation with computer"
2. Press **[Y/+]**, device with say "Ready…"
3. On computer, open ProRAE Suite 

4. Click Communications Tab, Setup Port

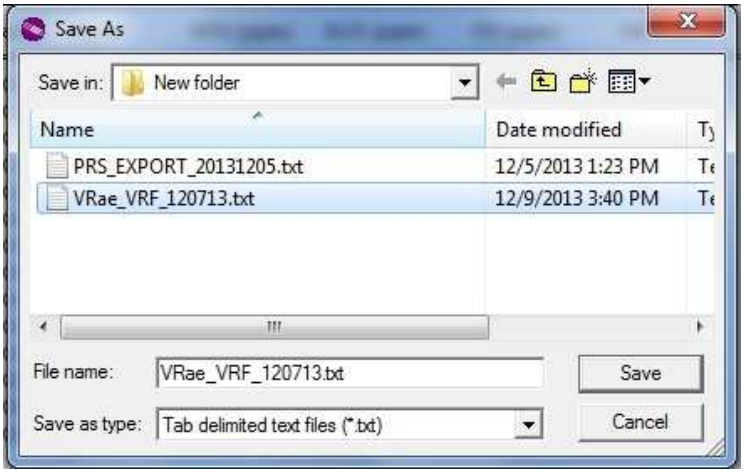

5. Depending on which USB port the device is plugged into, click COM X. (There should only be one available to click. It might be in the drop down bar like in the picture.)


6. Click OK

7. Click Communications Tab, Receive Data
8. Click OK, Data will transfer to computer
9. Click Event that corresponds to start time of desired data

10. Click Option Tab, Export Text…

11. File Directory: Desktop -> Swine Barn Data Downloads - Raw -> “Start Date” -> VRae
12. Name file: *VRae_DeviceID_Date* (example of data collected on device VRF on December 7, 2013: VRae_VRF_120713.csv)



13. Click Save
    a. Post-Processing will be done for these files later (change to csv, and split columns)
14. Copy data to flash drive
15. Quit ProRAE Suite

   a. Click No to “save changes to data”
16. On VRae, hit **[MODE]** to stop communication with computer
17. Press and hold **[MODE]** and **[N/-]** to enter calibration mode
18. Hit **[N/-]** until screen “View or Change Datalog?”
19. Hit **[Y/+]**
20. Hit **[N/-]** until screen “Clear all data?”
21. Hit **[Y/+]**, screen will say “Are you sure?”
22. Hit **[Y/+]**, “Data Cleared”
23. Hit **[MODE]** until datalog resumes
24. Hold **[MODE]** for 5 seconds to shutdown VRae

Appendix C. Raw Data

24-hour NH_3 concentration data

			Ammonia, ppm						
Date	Code		A	B	C	D	E	F	Mean
Dec 13-14	B1	Mean	6.2	2.2	5.0	7.5	4.9	4.2	5.0
		stdev	0.9	0.6	0.7	0.9	0.7	0.6	0.7
Dec 16-17	B2	Mean	-	5.1	6.2	8.1	5.2	4.0	5.7
		stdev	-	0.7	1.2	1.5	0.9	0.7	0.9
Dec 18-19	B3	Mean	6.6	5.4	6.3	8.3	5.2	4.5	6.1
		stdev	1.3	1.3	1.6	1.5	1.2	0.9	1.2
Dec 21-22	APC1	Mean	5.3	4.8	9.0	6.9	5.0	-	6.3
		stdev	1.1	0.8	2.2	1.1	0.8	-	1.2
Dec 26-27	APC2	Mean	7.6	8.1	15.6	13.0	8.3	-	10.5
		stdev	1.0	0.9	2.0	1.8	0.9	-	1.2
Dec 31-Jan	APC3	Mean	0.0	0.0	0.0	0.0	0.0	0.4	0.1
		stdev	0.0	0.0	0.1	0.2	0.0	0.2	0.1
Jan 10-11	APC4	Mean	1.81	2.28	4.66	-	2.16	1.59	2.5
		stdev	0.89	1.08	2.26	-	1.02	0.74	1.17
Jan 17-18	APC5	Mean	7.6	7.7	17.1	-	10.5	6.0	9.8
		stdev	1.1	1.1	2.5	-	1.8	1.0	1.4
Jan 20-21	APC6	Mean	10.3	12.1	17.4	7.8	15.0	-	11.6
		stdev	1.4	1.5	1.7	0.9	1.4	-	1.6
			ADJUSTED values based on both colocation (regressed to mean)						
		Mean							
Jan 22-23	P1	stdev	14.1	16.1	11.4	8.9	11.4	-	
		Mean	3.3	3.5	3.8	1.9	2.1	-	
Jan 24-25	P2	stdev	10.1	12.3	9.5	9.9	10.8	-	10.5
		Mean	1.4	1.9	1.4	1.8	1.6	-	1.4
Jan 26-27	P3	stdev	18	14.4	11.7	16.7	12.9	-	14.7
			4.88	3.07	1.83	2.38	2.25	-	2.63
Jan 28-29	APC7	Mean	16.6	15.7	18.5	16.3	15.3	-	16.5
	(adjusted ammonia)	stdev	3.79	3.63	4.55	2.98	4.53	-	3.79
Feb 3-4	APC8	Mean	17.6	18.2	9.8	18.5	18.9	-	16.6
	(adjusted ammonia)	stdev	3.6	3.5	0.8	2.9	2.2	-	2.4
Feb 10-11	APC9	Mean	28.7	26.0	-	-	29.5	-	28.1
	(adjusted ammonia)	stdev	5.9	5.4	-	-	6.0	-	5.7
Feb 17-18	APC10	Mean	7.6	7.8	9.7	7.8	8.6	10.9	8.7
	(adjusted ammonia)	stdev	1.0	0.8	0.9	1.1	1.2	1.2	0.9
Feb 24-25	APC11	Mean	14.0	9.4	9.8	10.2	9.1	7.7	10.0
	(adjusted ammonia)	stdev	2.3	1.4	0.9	1.1	0.9	0.5	1.0
Feb 26-27	P4	Mean	7.0	6.9	-	6.2	6.5	9.7	7.2
	(adjusted ammonia)	stdev	1.0	1.0	-	1.0	1.0	1.4	0.9

24-hour CO_2 concentration data

CO2									
Date	Code		A	B	C	D	E	F	Mean
Dec 13-1	B1	Mean	2260	2073	2157	2173	2092	2306	2177
		stdev	198	162	206	140	142	144	142
Dec 16-1	B2	Mean	2456	2369	2377	2422	2381	2634	2440
		stdev	224	180	247	174	168	204	176
Dec 18-1	B3	Mean	2002	1902	1913	2029	2067	2258	2029
		stdev	259	220	239	208	189	199	185
Dec 21-2	APC1	Mean	2275	2055	2207	-	2213	2457	2242
		stdev	247	188	189	-	195	223	183
Dec 26-2	APC2	Mean	2202	2051	2166	2254	2240	2590	2250
		stdev	257	197	202	171	157	192	173
Dec 31-J	APC3	Mean	2430	2149	2237	2345	2211	2286	2276
		stdev	123	90	140	134	95	138	99
Jan 10-11	APC4	Mean	2027	1865	1889	2024	1953	2184	1990
		stdev	228	204	197	181	209	237	196
Jan 17-1	APC5	Mean	2652	2526	2526	2696	2588	2698	2614
		stdev	243	256	268	215	268	252	235
Jan 20-2	APC6	Mean	2313	2226	1992	2404	2112	2453	2333
		stdev	467	412	247	401	214	420	421
Jan22-2	P1	Mean	2835	2793	2695	2797	2714	2972	2801
		stdev	253	240	262	237	210	236	227
Jan 24-2	P2	Mean	2247	2125	2128	2265	2202	2558	2254
		stdev	344	320	338	302	302	328	307
Jan 26-2	P3	Mean	2395	2313	2239	2420	2334	2660	2394
		stdev	378	376	340	346	302	338	327
Jan 28-2	APC7	Mean	2933	2783	2805	2945	2816	3159	2907
		stdev	279	263	256	237	290	301	257
Feb 3-4	APC8	Mean	2810	2597	2662	2700	2737	3047	2759
		stdev	351	302	329	289	295	315	297
Feb 10-1	APC9	Mean	3199	2947	3114	3056	3002	3298	3103
		stdev	274	255	269	250	263	294	257
Feb 17-1	APC10	Mean	2495	2328	2384	2479	2578	2768	2505
		stdev	249	233	261	195	195	225	203
Feb 24-2	APC11	Mean	2760	2546	2597	2576	2611	2746	2628
		stdev	234	179	227	188	184	246	185
Feb 26-2	P4	Mean	3121	2946	2954	2891	2901	3226	3007
		stdev	271	248	261	221	239	314	237

Appendix D: Shapiro-Wilk Normality Test Results

The results of the UNIVARIATE PROCEDURE to determine whether NH_3 and CO_2 concentrations were normally distributed. The test was run using SAS v. 9.3 (SAS Institute Inc., Cary, NC). Sample outputs are included below:

24-hour NH_3:

Tests for Normality				
Test	**Statistic**		**p Value**	
Shapiro-Wilk	W	0.861336	Pr < W	0.1938
Kolmogorov-Smirnov	D	0.255133	Pr > D	>0.1500
Cramer-von Mises	W-Sq	0.069962	Pr > W-Sq	0.2395
Anderson-Darling	A-Sq	0.423779	Pr > A-Sq	0.2135

24-hour CO_2:

Tests for Normality				
Test	**Statistic**		**p Value**	
Shapiro-Wilk	W	0.938419	Pr < W	0.6245
Kolmogorov-Smirnov	D	0.227306	Pr > D	>0.1500
Cramer-von Mises	W-Sq	0.052825	Pr > W-Sq	>0.2500
Anderson-Darling	A-Sq	0.29681	Pr > A-Sq	>0.2500

Appendix E: Analysis of Concentrations by APC Status

The results of the PROC GLM to determine whether NH_3 and CO_2 concentrations were significantly different by APC status. The test was run using SAS v. 9.3 (SAS Institute Inc., Cary, NC). Sample outputs are included below:

8-hour NH_3:

Source	DF	Type I SS	Mean Square	F Value	Pr > F
APC	1	19.90796666	19.90796666	0.49	0.4956

8-hour CO_2:

Source	DF	Type I SS	Mean Square	F Value	Pr > F
APC	1	21035.71133	21035.71133	0.19	0.6717

Appendix F: Analysis of Concentrations by Shift

The results of the PROC GLM to determine whether NH_3 and CO_2 concentrations were significantly different by shift. The test was run using SAS v. 9.3 (SAS Institute Inc., Cary, NC). Sample outputs are included below:

8-hour NH_3 APC Off:

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Shift	2	109.5248424	54.7624212	3.41	0.0365

8-hour NH_3 APC On:

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Shift	2	265.9066538	132.9533269	1.60	0.2059

8-hour CO_2 APC Off:

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Shift	2	99234.52264	49617.26132	0.36	0.6998

8-hour CO_2 APC On:

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Shift	2	266781.4729	133390.7365	1.05	0.3534

Appendix G: Analysis of Concentrations by Position

The results of the PROC GLM to determine whether NH_3 and CO_2 concentrations were significantly different by position. The test was run using SAS v. 9.3 (SAS Institute Inc., Cary, NC). Sample outputs are included below:

24-hour NH_3 APC Off:

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Position	5	59.95514027	11.99102805	0.77	0.5792

24-hour NH_3 APC On:

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Position	5	287.8135191	57.5627038	0.73	0.6053

24-hour CO_2 APC Off:

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Position	5	465696.5517	93139.3103	0.76	0.5873

24-hour CO_2 APC On:

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Position	5	762812.2758	152562.4552	1.31	0.2741

References

Anthony, T.R., R. Altmaier, J.H. Park, and T.M. Peters. (2013). Modeled effectiveness of ventilation with contaminant control devices on indoor air quality in swine farrowing facility. *J Occ and Environ Hyg*

Anthony, R., Altmaier, R., Jones, S., Gassman, R., Park, J., & Peters, T. (2015). Use of recirculating ventilation with dust filtration to improve wintertime air quality in swine farrowing room. *J Occ Environ Health,* (in press).

Basinas, I., Schlünssen, V., Takai, H., Heederik,D., Omland, Ø.,Wouters, I.M., Sigsgaard, T., and Kromhout, H. (2013). Exposure to inhalable dust and endotoxin among Danish pig farmers affected by work tasks and stable characteristics. *Ann Occ Hyg* 1–15, doi: 10.1093/annhyg/met029.

Cormier, Y., & Israel-Assayag, E. (2004). Chronic inflammation induced by organic dust and related metabolic cardiovascular disease risk factors. *Scand J Work Environ Health, 30*(6), 438-444.

Donham K., Haglind, P., Peterson, Y., Rylander, R., Belin, L. (1989). Environmental and health studies of farm workers in Swedish swine confinement buildings. *Brit J Ind Med*, 46:31-37.

Donham K. J. (1991). Association of environmental air contaminants with disease and productivity in swine. *Am J Vet Res*, 52 (10), 1723-1730.

Donham K, Reynolds SJ, Whitten P, Merchant JA, Burmeister L, Popendorf WJ. (1995). Respiratory dysfunction in swine production facility workers: dose-response relationships of environmental exposures and pulmonary function. *Am J Ind Med*, 27, 405-418.

Guidotti, T.L. (1996). Hydrogen Sulphide. *Occup Med,* Vol. 46, No. 5. pp. 367-371.

Honeyman, M.S. (1996). Sustainability Issues of U.S. Swine Production. *J. Anim. Sci*. 74:1410–1417

Iversen M, Kirychuk S, Drost H, Jacobson L. (2000). Human health effects of dust exposure in animal confinement buildings. *J Agric Saf Health*. Nov;6(4):283–288.

Jerez, S. B., Zhang, Y., McClure, J.W., Heber, A. J., Ni, J., Koziel, J.A., Hoff, S.J., Jacobson, L.D., and D. Beasley, D. (2005). Aerial pollutant concentration and emission rate measurements from a swine farrowing building in Illinois. Proc. of the 2005 AWMA Annual Meeting and Exhibition. Minneapolis, Minn.

Legator, M.S., Singleton, C.R, Morris, D.L., Philips, D.L. (2001). Health effects from chronic low-level exposure to hydrogen sulfide. *Arch Environ Health* 56:123–137

Malmberg, P. (1990) Health Effects of Organic Dust Exposure in Dairy Farmers. *Am J Ind Med*, 17:7-15.

Malmberg, P., Larsson, K., (1993). Acute exposure to swine dust causes bronchial hyperresponsiveness in healthy subjects. *Eur Resp J*, 6, 400-404.

New York State Department of Health (NYDOH). (2004). *The Facts about Ammonia.* Retrieved May, 2015 from https://www.health.ny.gov/environmental/emergency/chemical_terrorism/ammonia_tech.htm

O'Shaughnessy, P. T., Donham, K. J.Peters, T. M. (2010). A task-specific assessment of swine worker exposure to airborne dust. *J Occ Environ Hyg*, 7: 7–13.

Park JH, Peters TM, Altmaier R, Sawvel RA, Anthony TR. (2013). Simulation of air quality and cost to ventilate swine farrowing facilities in winter. *Computers and Electronics in Agriculture*. 98:136-145.

Pedersen, B., Iversen, M., Bundgaard Larsen, B., & Dahl, R. (1996). Pig farmers have signs of bronchial inflammation and increased numbers of lymphocytes and neutrophils in BAL fluid. *Eur Respir J, 9*(3), 524-530.

Radon, K., Weber, C., Iversen, M., Danuser, B., Pedersen, S., & Nowak, D. (2001). Exposure assessment and lung function in pig and poultry farmers. *Occup Environ Med, 58*(6), 405-410.

Rahman, S., DeSutter, T., Zhang, Q. (2011). Efficacy of a microbial additive in reducing odor, ammonia, and hydrogen sulfide emissions from farrowing-gestation swine operation. *Agric Eng Int: CIGR Journal*, 13(3).

Reeve, K.A., T.M. Peters, and T.R. Anthony**.** (2013). Wintertime factors affecting contaminant distribution in a swine farrowing room. *J Occ Environ Hyg* 10:287–296.

Reynolds, S.J., Donham, K.J., Whitten, P., Merchant, J.A., Burmeister, L.F., Popendorf, W.J. (1996). Longitudinal evaluation of dose-response relationships for environmental exposures and pulmonary function in swine production workers. *Am J Ind Med*, 29:33-40.

Rule, A.M., A.R. Chapin, S.A. McCarthy, K.E. Gibson, K.J. Schwab, and T.J. Buckley. (2005). Assessment of an aerosol treatment to improve air quality in a swine concentrated animal feeding operation (CAFO). *Environ Sci Tech* 39:9649–9655.

Ryer-Powder, J. E. (1991). Health Effects of Ammonia. *Plant/Oper Prog*, *10*, 228-232.

Rylander, R., Essle, N., Donham, K.J. (1990). *Am J Ind Med*, 17:66-69.

Samet, J.M., Marbury, M.C., and Spengler, J.D. (1987). Health Effects and Sources of Indoor Air Pollution. Part I. *Am Rev of Resp Dis*, Vol. 136, No. 6 (1987), pp. 1486-1508.

Senthilselvan A, Dosman JA, Kirychuk SP, Barber EM, Rhodes CS, Zhang Y, Hurst TS: Accelerated lung function decline in swine confinement workers. (1997) *Chest*, 111, 1733-1741.

Sun, G., H. Q. Guo, and J. Peterson. (2010). Seasonal odor, ammonia, hydrogen sulfide, and carbon dioxide concentrations and emissions from swine grower-finisher rooms. *Journal of the Air & Waste Management Association*, 60(4): 471-480.

Townsend, C.L., and Maynard, R.L. (2002). Effects on health of prolonged exposure to low concentrations of carbon monoxide. *Occup Environ Med* 2002;59:708-711

United States Department of Agriculture (USDA). Census of Agriculture. (2012) Retrieved January 2015 from http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Highlights/Hog_and_Pig_Farming/

US Environmental Protection Agency. *Pork Production*. Retrieved July 2015 from http://www.epa.gov/oecaagct/ag101/printpork.html

US National Laboratory of Medicine (NIH). *Carbon Dioxide.* Retrieved May 2015 from http://toxtown.nlm.nih.gov/text_version/chemicals.php?id=6

Zejda JE, Hurst TS, Barber EM, Rhodes C, Dosman JA. (1993). Respiratory health status in swine producers using respiratory protection devices. *Am J Ind Med*. 23:743-750.